THE CONSEQUENCES OF DELAYED WATER INFRASTRUCTURE INVESTMENTS IN DEVELOPING COUNTRIES

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ABSTRACT

Jane Junlan Zhao: The Consequences of Delayed Water Infrastructure Investments in Developing Countries
(Under the direction of Dale Whittington)

Over one-third of infrastructure projects that are started are not finished and many more face delays. However, the consequences of delayed water projects have not been studied closely. My five-paper dissertation examines key economic and policy questions under conditions of poor water supply and delayed infrastructure investment in Kathmandu, Nepal.

In my first paper, I estimate household costs of water infrastructure delay. I compare coping costs borne by 1,500 households in 2001 and 2014. I find that coping costs more than doubled due to significant capital investments and expenditures. There is a relationship between poor reliability and higher coping costs, and infrastructure delays can have significant household economic and financial costs.

My second paper explores how the reliability of piped water services affects household time use using time diaries. I examine the relationship between piped water reliability and time spent collecting water and other activities. I show that under conditions of intermittent water supply, increased reliability is related to increased time collecting water.

In my third paper, I examine household preferences around water tariff structure and fair prices. I jointly estimate household preferences for increasing block tariffs and fixed charges in a seemingly unrelated probit model. I ask respondents what they think a "fair water bill" is for a randomly assigned quantity. I find that households support a water tariff that increases with the quantity of water, but there is no evidence suggesting households support increasing block tariffs.

My fourth paper examines the market structure and firm operations of small-scale private water vendors in Kathmandu Valley. I estimate city-wide flows of water and money and assess firm profitability. I find that water vendors supply 20% of the water for households and businesses in Kathmandu. Additionally, the vending market seems to be competitive.

My final paper reviews the hedonic property value model and its application in developing countries in estimating demand for piped water. Market premiums vary from -$39 to $938 per month. 37% of market premiums are not statistically significant. Hedonic estimates are sensitive to research methods and design and are larger than estimates using other valuation techniques.

For Maya

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LIST OF ABBREVIATIONS & SYMBOLS

ADB	Asian Development Bank
AIC	Akaike information criteria
CBS	Central Bureau of Statistics
DHS	Demographic and Health Survey
EBIT	earned income before interest and taxes
EBITDA	earned income before interest, taxes, depreciation, and amortization
GWI	Global Water Intelligence
h/d	hours per day
HPVM	hedonic property value model
IBTs	increasing block tariffs
IMF	International Monetary Fund
KUKL	Kathmandu Upatyaka Khanepani Limited
KVWSM	Kathmandu Valley Water Supply Management
Lpcd	liters per capita per day
LSMS	Living Standard Measurement Survey
m	month
min	minute
MLD	million liters per day
MWSP	Melamchi Water Supply Project
NBWIA	Nepal Bottled Water Industries Association
NLFS	Nepal Labor Force Survey
NPR	Nepalese rupee
NWSC	Nepal Water Supply Corporation
O&M	operation and maintenance
OECD	Organisation for Economic Co-operation and Development

OLS	ordinary least squares
PPP	purchasing power parity
PSU	primary sampling unit
PWCs	private water connections
RP	revealed preference
SD	standard deviation
SP	stated preference
UNDESA	United Nations Department of Economic and Social Affairs
UNICEF	United Nations Children's Fund
US	United States
USD	US dollar
VAT	value-added tax
VDC	Village Development Committee
VDWTEA	Valley Drinking Water Source and Tanker Entrepreneurs Association
WHO	World Health Organization
WTP	willingness to pay

CHAPTER 1: INTRODUCTION

In the last three decades, significant progress has been made towards providing sustainable access to improved drinking water sources for the world's population (WHO and UNICEF, 2017). However, there remains a critical gap in the supply of clean, reliable drinking water. With climate change, rapid population growth and urbanization, existing water supply systems and resources are becoming more stressed. Investments in water supply have not kept pace with the need for piped water in cities (OECD, 2016). When development projects do get funded, there are still large challenges. Over one-third of infrastructure projects that are started are not finished (Williams (2017), Rasul and Rogger (2018) in Bancalari (2020)), and many more face delays or temporary abandonment (e.g., 60% of sewerage projects in Peru (Bancalari, 2020)). As such, the average project is burdened by both cost overruns and benefit reductions (Flyvbjerg, 2016).

While there are many economic studies that illustrate the effects of completed water infrastructure projects (Duflo and Pande, 2007; Meeks, 2017; Alsan and Goldin, 2019; Sequeira et al., 2019), there are two key gaps. First, the consequences of delayed and abandoned water infrastructure projects have not been examined closely. Second, the current economic and policy research on water supply has been mostly cross-sectional and piece-meal, focusing on either households, small businesses, or water utilities, often with a singular geographic focus.

For the first gap, there are many unanswered questions. What happens to a city's inhabitants when investments are delayed? Under these conditions, how can policymakers and utility managers work with households to recover costs that are direly needed? With a gap in public supply, what role does the private sector play in water provision? When households and firms adapt, what does that mean for the delayed project and future projects?

A few clues about the consequences of delayed water infrastructure can be found in related literature. There is a nascent literature focusing on intermittency (Andey and Kelkar, 2009; Ercumen et al., 2015; Burt et al., 2018) and age of water pipes (Bhalotra et al., 2018). Bancalari (2020) finds that early-life mortality increases with unfinished sanitation projects due to cuts in water supply during installation, stagnant water in excavation pools, and large building sites that divert heavy traffic to residential areas. Historical analysis of piped water, sanitation, and chlorination provides some understanding of differences between early and late adopters. In Finland, for example, a delay in adoption by smaller cities and towns resulted in more effective investments with higher measurable returns, "when necessary complementary aspects of development had already improved" (Peltola and Saaritsa, 2019). These works indirectly illustrate mechanisms by which delayed infrastructure investments can affect households. Broader impacts of project delays – social, political, and economic – remain not well documented.

For the second gap, there is limited knowledge around how household behaviors, investments, and preferences change over time; market structures of private water vendors; and the role of local contexts. A major barrier to the holistic study of water systems is the lack of complementary datasets, collected over time. As a result, it has been difficult to study dynamics within one water supply ecosystem and then make appropriate policy and investment decisions. To increase the effectiveness of investments in large development projects, decision makers need a more holistic understanding of a project's consequences: intended and unintended, present and future, for households and businesses.

My dissertation seeks to fill these two gaps in the literature. In five chapters, I examine key economic and policy questions related to water services under difficult conditions. In the first four chapters, I study households and small scale private water vendors under conditions of a long-delayed infrastructure project, a municipal water utility failing to deliver adequate water to its users, and a rapidly growing urban population. These four chapters use Kathmandu as an illustrative example and build upon work done in Kathmandu Valley, Nepal, in 2001. By following the same set of households, I am able to better understand the changing effects of a delayed infrastructure project with a deteriorating municipal water supply.

Kathmandu Valley is an extreme example of urban water supply. Nepal is one of the fastest urbanizing countries in the world (UNDESA, 2014) and also one of the poorest (World Bank, 2019). As a result, the Kathmandu's water utility is under tremendous stress to expand supply quickly, with few resources. Kathmandu has one of the worst performing water utilities in Asia, with little to no households having 24-hour service (Andrews and Yñiguez, 2004). There is an estimated supply gap of 75% in the dry season – with 90,000 cubic meters supplied of the 360,000 cubic meters demanded (Bhandari, 2014).

The inadequacy of in-valley water resources to meet long-term demand was identified almost 50 years ago (Ching, 2018). The Melamchi Water Supply Project – with a 26.5 km long tunnel diverting 170 MLD from the Melamchi River to Kathmandu – was identified as a solution in 1988 (Binnie and Partners, 1988), with feasibility studies conducted from 1990 to 1992 (Snowy Mountain Engineering Consultants, 1992). The Nepalese Civil War prevented much development from occurring in the 1990s. In 2000, the Asian Development Bank awarded a loan of $464 million to Nepal to implement the MWSP. Since then, the project has faced many challenges (Ching, 2018): failure to attract a private operator, withdrawal of key funders, public opposition to privatization (Domènech et al., 2013; Dhar, 2007), issues with contractors since beginning construction in 2009 (e.g., failure to carry out work as scheduled, payment conflicts). As of January 2021, the residents of Kathmandu Valley continue to wait for the completion of the Melamchi Water Supply Project.

As an extreme case of water supply, Kathmandu provides research opportunities to (1) gain pre-theoretical descriptive knowledge, (2) advance theoretical understanding, and (3) allow for preliminary assessment of new theoretical ideas before further theoretical or empirical work (Büthe, 2015). I leverage these opportunities to examine household coping costs over time, time use patterns, and water tariff structure preferences. I also build a typology of water vendors and assess firm profitability and competitiveness. In the last chapter, I develop a framework for understanding hedonic valuation of piped water connections in low and middle income countries. Then I assess the reliability and accuracy of the measurements through conducting a meta-analysis. I provide brief overviews of each chapter below.

Chapter 2 illustrates and quantifies the economic and financial costs of delays in water supply infrastructure investments. We compare coping costs borne by 1,500 households in 2001 and 2014 to systematically understand how household behaviors, economic costs, and water sources have changed over time. This chapter makes two important contributions. It is the first to empirically document how coping costs and strategies have changed over an extended period under conditions of rapid population growth, increased water shortages, and delayed public infrastructure investment. Second, our advantageous research design allows us to control for time-invariant household-level unobservables, strengthening the validity of our analysis of the determinants of coping behaviors and costs.

This study estimates costs associated with five main coping behaviors: (1) water collection time, (2) private well installation and operation, (3) water storage and rainwater collection, (4) in-house water treatment, and (5) payments to private water vendors and other informal suppliers. This study uses survey data collected from 1,500 households from 2001 and then resurveyed in 2014. This chapter presents summary statistics of the coping costs, broken down into the five main behaviors and households with/without private water connections and private wells. Results from a multivariate analysis explaining the changes in household coping costs are also presented. The covariates include household demographic characteristics, water source characteristics, quality perceptions, and policy preferences.

The third chapter builds upon the second chapter's findings around decreased water collection time. The first study finds a dramatic decline in time spent collecting water that are accompanied by increases in (1) household investments in water storage and private wells and (2) expenditures on vended water. The second study explores how the reliability of piped water services affects household time use – focusing on tradeoffs between water collection and labor, chores, and leisure. This work fills two gaps in the literature. First, little is known about how access to tap water affects allocation of daily time spent across multiple categories, including time spent collecting water both inside and outside the home, labor, chores, leisure, sleep. Second, there is a nascent literature on intermittent water supply that examines the impacts of quality and reliability of a piped water connection.

In this chapter, we use 2014 survey data from the same 1,500 households as in Chapter 2, of which 819 households reported time diaries. We ask household members to keep a time diary of a typical 24-hour day, in 30-minute blocks. Additionally, we include variables related to water collection times, consumption, and reliability in our analysis. First, we present descriptive analyses. We examine the profile of water collections and water collection time patterns throughout the day. We focus on the relationship between work (hours worked, employment) and water collection – using (1) visual examinations of time use graphs and (2) regression analysis. We also examine water collection's relationship with other activities – chores and leisure. Then, we compare daily time use patterns of households with different types of water supply (with or without a private well, reliable or unreliable private water connection) using visual examinations of time use graphs and descriptive statistics. Second, we use OLS regressions to estimate the correlation between water collection time, water consumption, and water connection reliability. We also include robustness checks. We find that when tap water connections are more reliable, households spend more time on collecting water.

The fourth chapter shifts from examining household behaviors to household preferences around water tariffs. There is a consensus among water utility managers and international donors that increasing block tariffs are best suited to balancing the multiple policy objectives of tariff design. This notion is being challenged by researchers using simulations and empirical analysis (Whittington et al., 2015; Fuente et al., 2016). However, household preferences have been neglected – neither elicited by tariff designers nor studied by researchers. This chapter addresses this gap by directly asking the 1,500 households surveyed in 2014 about their preferences regarding key attributes of a water tariff. We collected information on households' knowledge, attitudes, and perceptions about the water services in Kathmandu, as well as households' urban environmental and infrastructure priorities. Using a seemingly unrelated probit model, we jointly estimate household preferences for increasing block tariffs and fixed charges. We also asked respondents what they thought a "fair water bill" would be for a randomly assigned fixed quantity of water. We analyzed these answers to determine whether respondents had a preference for increasing nonlinear tariff structures. We find that respondents support monthly water bills that increase linearly as the quantity of water use increases.

This study is the first to directly ask households about their preferences regarding water tariffs and their structure, as well as their reasoning behind their preferences. As water pricing can present political risks, utility managers and politicians should not ignore household preferences. Additionally, households may be more likely to pay their bills and support a water utility that uses a tariff structure that is consistent with their preferences. Kathmandu's water tariff at the time of the study was an increasing block tariff, typical of many utilities around the world. Our study challenges and tests two assumptions that tariff designers have made. First, that the water tariff structure selected by experts is consistent with household objectives. Second, that household objectives are equity, fairness, affordability, and economic efficiency.

Chapter 5 enriches our depiction of water supply in Kathmandu Valley by examining small-scale private water vendors. From Chapters 2 and 3, we build an understanding of the role vended water plays in household water supply. However, we are left with questions about the water vending sector, beginning with a basic understanding of market structure and firm operations.

Additionally, with unregulated private provision of essential services, there are concerns around firm profitability and market competitiveness. In this chapter, we examine the structure and complexity of the water vending supply chain. We use a mixed-methods research approach that incorporates data from structured household and vendor surveys as well as key informant interviews. First, we estimate city-wide flows of water and money, focusing on different points in the water vending supply chain. Through this exercise, we are able to build a typology of the types of water vendors that operate in Kathmandu. Second, we construct monthly accounts of revenues and costs using standard financial accounting methods. We are then able to assess firm profitability using four quantitative metrics and infer market competitiveness.

With continued delays in infrastructure investment and deteriorating public water supplies, both private household capital investment and private water vendors begin to play a larger role. As a result, the system of water supply transforms, and the direct and indirect benefits and costs of the initial infrastructure project may no longer be representative. As vended water becomes more ubiquitous, does demand for piped water infrastructure change? Is vended water a stopgap measure? If so, how does it affect social and political pressure to complete the infrastructure project? Households may become accustomed to using vended water – does it affect long-term demand for piped water and confidence in the water utility to provide safe water? Can and will vended water become a sustainable and efficient part of a city's water supply? The sight of water tanker trucks and bottled water is becoming more common across cities in the developing world. There remain many questions around the future of vended water and its effects on households. This study lays the groundwork for future research by carefully and systematically building an understanding of the water vending sector in one city.

The final chapter moves away from Kathmandu and highlights the importance of building a holistic understanding of a water supply system. This study presents the first meta-analysis of a revealed preference method – hedonic property value model – for estimating demand for piped water in middle and low income countries. Comprehensive reviews have been conducted for stated preference studies on household demand for improved water services (e.g., van Houtven et al. (2017)), but there have not been any conducted for revealed preference studies. This study fills this gap by assessing the validity and reliability of the hedonic method. Existing market premiums from hedonic studies vary widely, from -$1.26 per month to $938 per month; 37% of market premiums found are also not statistically significant. I identify common challenges and solutions for improving the accuracy of the hedonic method when used to estimate demand for piped water in developing countries. Its contributions are two-fold. First, I build a theoretical framework for systematically thinking through what goes into the hedonic estimate of household demand for piped water. This provides a basis for assessing the quality of and interpreting results from research papers. Second, as a meta-analysis, I comprehensively review and synthesize results from hedonic studies. I also compare the results from the hedonic studies to those from stated preference and coping cost studies to assess validity and reliability.

Chapter 6 first describes the theoretical framework on which the meta-analysis is based. I then briefly examine the hedonic literature on drinking water from the United States. With this foundation, I develop expectations and hypotheses for its application in low and middle income countries. Moving to the meta-analysis itself, I systematically collect a set of 36 primary studies that provide 75 market premiums. For the meta-analysis, I use explanatory variables describing household characteristics, attributes of water supply, housing market characteristics; covariates related to research design and methods include research design, sample size, model specification, econometric methods, and quality variables such as having a research focus on water and date of publication. After assessing the hedonic valuation method for reliability and validity, I conclude with a checklist of suggested best practices for future hedonic valuation studies.

Together, these five chapters demonstrate the importance of understanding the deep complexities of urban water supply from multiple perspectives. This dissertation advances understanding of the economic costs and system-level consequences of deteriorating water supply and delayed public infrastructure investment on households and businesses. As policymakers, utility managers, and donors consider policies such as tariff reform, regulation of private water vendors, and future infrastructure investment, greater understanding of intended and unintended consequences can foster a more equitable, efficient, and sustainable system of water supply in Kathmandu and beyond.

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CHAPTER 2: THE COSTS OF DELAY IN INFRASTRUCTURE INVESTMENTS: A COMPARISON OF 2001 AND 2014 HOUSEHOLD WATER SUPPLY COPING COSTS IN THE KATHMANDU VALLEY, NEPAL[1]

2.1 Introduction

In 2001, we conducted a survey of 1500 randomly sampled households in Kathmandu to determine the costs people were incurring to cope with Kathmandu's poor quality, unreliable piped water supply system and to estimate their willingness to pay for improved piped water services [*Whittington et al.*, 2002; *Pattanayak et al.*, 2005]. At the time, there were two related policy and infrastructure changes under consideration that motivated our study. The first was the proposal to construct the Melamchi Water Supply Project (MWSP), a US$464 million package of infrastructure investments designed to bring water from the Melamchi River into the Kathmandu Valley [*Whittington et al.*, 2004]. The project involves an interbasin water transfer of about 170,000 m^3/d to be delivered through a 26 km long tunnel through a mountain. The second intervention being discussed by international donors was the possibility of engaging a private sector operator to manage the municipal water supply system. Both sets of projects, once completed, were expected to help improve piped water services in the Kathmandu Valley.

Our 2001 study found that about 70% of the residents of Kathmandu Valley had a connection to the piped distribution network, but they typically received nonpotable water for only 1–2 hours per day (h/d). Households were incurring coping costs of about US$5/month (m) (in 2014 prices), approximately 2% of household income. Our 2001 estimates of coping costs had five

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components: (1) the value of time spent collecting water, (2) pumping costs from private wells, (3) in-household water treatment costs, (4) storage costs, and (5) payments for water purchased from vendors and others. The largest of these components was the value of time spent collecting water from outside the home, and these time costs were higher for poor households than for non-poor households. These coping costs were almost twice as much as the typical water bill of households connected to the piped water network and about 20% of their stated willingness to pay for improved services (24 h/d, 7 days a week).

From 2001 until 2014, there was little additional investment in the municipal water supply system except for the MWSP. From 1996 until 2006, Nepal experienced political turmoil (the royal family was murdered by the Crown Prince) and civil war; as a result, there was rapid population growth in Kathmandu Valley due to massive in-migration. Additionally, Nepal's economy has been one of the slowest growing in South Asia, and there have been difficulties in negotiating financing for new investments in urban infrastructure. As a result, progress on the MWSP has been much slower than expected. After years of discussion, in 2000 the Asian Development Bank (ADB) and its partners finally agreed to finance the MWSP. However, the World Bank pulled its support in 2002, due in part to the government's failure to engage a private operator in the management of the municipal water supply system. Construction of the Melamchi tunnel did not begin until 2009. The project experienced further delays due to problems with the first contractor. At the time of our second survey in 2014, residents of Kathmandu still had not received any additional water supplies from outside the Kathmandu Valley. Most of these issues have now been resolved. New water supplies are expected to reach Kathmandu after the completion of Melamchi tunnel in 2017; associated investments in the rehabilitation and expansion of the water supply infrastructure in Kathmandu are scheduled for completion by 2020.

In the summer of 2014, we attempted to reinterview all 1500 households in our 2001 sample to determine how they managed to deal with the growing water shortage and the deteriorating condition of the piped water infrastructure in Kathmandu and to compare their coping costs in 2014 with those we first estimated in 2001. Our broad objective was to understand and quantify the costs to households of delaying investments in piped water supply infrastructure in a large, rapidly growing city in a low-income country. Kathmandu's experience over the 13 years from 2001 to 2014 is not unique. Because piped water supply infrastructure is so capital intensive [*Whittington et al.*, 2009], it takes time to design, finance, and build large projects, but political stability and economic growth are essential for sustaining the investment process and cannot be taken for granted. Many cities in developing countries have experienced similar "lost decades" of investment in water supply infrastructure due to financial crises, civil war, or political turmoil [*Swyngedouw*, 2004].

In section 2, we describe the water supply infrastructure in 2001 and how it changed up to 2014. Section 3 presents the background for understanding household decisions about coping costs, as well as a review of the literature on coping costs as an estimate of the benefits of environmental quality improvements more generally. Section 4 describes our modeling strategy and method for calculating coping costs. Section 5 discusses the 2014 fieldwork and presents a profile of sample households, contrasting their socioeconomic situation in 2001 and 2014. It also compares the water supply conditions of households in 2001 and 2014, both those connected to the piped water network and those that were not. In section 6, we then present the 2014 household coping costs estimates and compare these with our 2001 results. We also compare and contrast the 2014 coping costs of households with different water supply conditions and of different income groups. Section 7 presents the results of multivariate analyses of the factors associated with the change in coping costs from 2001 to 2014. Section 8 summarizes our conclusions about the costs of delay in the Kathmandu municipal water sector.

2.2 Background

In 2014, the population of Kathmandu Valley was approximately 2.7 million. The population of the urban areas of the Kathmandu Valley—Kathmandu metropolitan city, Lalitpur submetropolitan city and the municipalities of Kirtipur, Madhyapur, and Bhaktapur—have experienced especially rapid growth, from 674,000 in 2001 to 1,141,000 in 2014. Much of this increase was due to in-migration as people fled from the civil war in the rural areas and sought safety and better economic opportunities in the Kathmandu Valley [*Muzzini and Aparicio*, 2013]. The 2011 census reported that 44% of the total population in the valley was in- migrants from other parts of the country, mainly rural and other small urban areas [*Suwal*, 2014]. The population density of urban areas in the Kathmandu Valley increased as people crowded into the city, from 10,262 persons/km^2 in 2001 to 14,703 in 2011 [*Subedi*, 2014]. This in-migration was accompanied by unplanned construction on the edges of the city as agricultural lands in the valley were converted to urban uses, especially housing.

The Nepal Water Supply Corporation (NWSC) oversees the municipal water supply and sanitation sector in the Kathmandu Valley [*Bhandari*, 2014]. The NWSC is owned by government (30%), municipalities (50%), private entities (15%), and employees (5%) [*Bhandari*, 2014]. Kathmandu Upatyaka Khanepani Limited (KUKL) is the service operator and provider in the Kathmandu Valley, with a service area of 150 km^2 [*Bhandari*, 2014]. KUKL currently manages 35 surface sources, 59 tube wells, 47 ground reservoirs, and 21 treatment plants [*Bhandari*, 2014]. KUKL lacked both the funds and the institutional capacity to respond effectively to the growing water crisis in the Kathmandu Valley, but providing piped water and sewer services to this rapidly growing, unserved population would have challenged even a well-financed, well-managed water utility.

Over the past two decades, Nepal's economic growth rate has lagged most other countries in South and East Asia [*World Bank*, 2016]. Nevertheless, by global standards, over the past 5 years

Nepal's annual GDP growth rate has averaged a respectable 4.5%, and household incomes in Kathmandu have been steadily increasing [*World Bank*, 2016]. But this economic growth did not translate into significant increases in funding for the rehabilitation and expansion of KUKL's water and sanitation infrastructure. Little international donor assistance stepped in to fill the gap. From 2002 to 2004, KUKL received a grant from Japan for about US$25 million to improve KUKL's municipal water facilities (i.e., the Manohara Water Treatment Plant, Min Bhawan and Singha Durbar Elevated Tanks, and the distribution line from the Shaibhu Reservoir to Lalitpur) [*Kathmandu Upatyaka Khanepani Limited*, 2015]. Aside from the ADB's support of the MWSP, this was the only significant foreign assistance to the municipal water sector.

The origins of the MWSP date back to Kathmandu's 1973 Water Master Plan, which identified the need for new out-of-valley raw water sources [*Binnie and Partners*, 1973]. The Master Plan argued that in-valley water sources were inadequate to meet long-term needs and that out-of-valley sources should be studied [*Binnie and Partners*, 1973]. Feasibility studies were conducted from 1988 to 1992 [*Binnie and Partners*, 1988; *Snowy Mountain Engineering Consultants*, 1992] on the option of bringing water from Melamchi River, situated outside the valley, through a 26 km-long tunnel. The first phase of this project was estimated to be able to supply an extra 170,000 m^3/d and subsequent phases up to a total of 500,000 m^3/d [*Pant et al.*, 2008].

In 2000, the ADB awarded a loan to Nepal to help finance the US$464 million MWSP, conditional on institutional reforms, which included a private operator [*Domenech et al.*, 2013]. Failure to attract private bidders resulted in a long delay in the MWSP. The ADB approved a major restructuring of the financing package for the MWSP, allowing the project to move forward [*Domenech et al*., 2013]. The private sector participation requirement was removed, as well as some of the social development initiatives in the original project [*Asian Development Bank* (*ADB*), 2008]. The ADB provided a US$137 million loan, Japan Bank for International Cooperation provided an additional US$47.5 million, and several other donors participated in the financing with smaller amounts [*ADB*, 2008]. The government of Nepal promised to provide domestic counterpart financing of US$90.6 million. The revised project was estimated to cost US$317 million [*ADB*, 2008]. Originally, this revised MWSP was to be completed by the summer of 2016, but contractor delays and the 2015 earthquakes have pushed back the completion date to 2017.

The result of this low level of investment in the municipal water supply infrastructure during this period has been that by 2014 urban residents of the Kathmandu Valley faced acute and recurrent water shortages and deteriorating water quality. Although KUKL managed to increase the number of residential connections from 167,000 in 2008, to 195,000 in 2013 [*Kathmandu Upatyaka Khanepani Limited* (*KUKL*), 2014], the total amount of water supply did not increase as the additional raw water from the MWSP had not yet arrived. KUKL [2014] estimates that it needs 360,000 m^3 of water per day to supply its existing customers. However, KUKL [2014] is only able to supply 150,000 m^3/d in the wet season and 90,000 m^3/d in the dry season. Thus, even when the first phase of the MWSP is completed, KUKL will still not be able to supply 360,000 m^3/d.

Households have responded in two main ways to KUKL's inability to increase supplies. First, many drilled private wells to supplement their water supply from KUKL's piped network. Second, households began purchasing increasing quantities of water from a new, rapidly growing private water vending industry. In 2001, there were only about 60–70 tankers in the Kathmandu Valley, with most operated by KUKL. By 2004, the number of tankers had grown to about 160, and five large-capacity boreholes had been drilled to supplement the tanker trucks' use of natural water sources. Between 2004 and 2008, the number increased by an additional 500 tankers. By 2014, 210 firms engaged in water vending and operated about 700 water tankers.

In 2014, there were also approximately 200 bottled water firms in Kathmandu selling water mostly in 20 L plastic bottles ("jars"), in addition to the smaller 1 L bottles. In 2004, there were only about 5 bottled water enterprises. The Nepal Bottled Water Association (a trade association with

160 of the 200 registered firms in Kathmandu Valley) reports that today, only 25% of the drinking water used by households is supplied by KUKL.

In summary, from 2001 to 2014 the private sector has stepped in to meet the growing household demand for improved water services. In the next sections of the paper we describe in more detail what these changes have meant to households in terms of increased monthly costs and inconvenience.

2.3 A Review of the Theory and Literature on "Coping Costs"

The theory underlying the relationship between the coping costs that a household incurs in dealing with unreliable, nonpotable water supplies and its demand for improved water supplies comes from the environmental economics literature on the measurement of the benefits and costs of pollution control [*Mäler,* 1974; *Mäler and Wyzga*, 1976*; Cropper and Oates*, 1992]. The costs of coping, or averting, behaviors (such as purchasing air conditioners to reduce exposure to air pollution) are used to estimate the value of environmental quality improvements.

We present a simple theoretical framework to illustrate the relationship between coping costs and the economic benefits of improvements in a public water supply system. We follow closely the approach described in Pattanayak et al. [2005]. We assume the household has a health production function, and seeks to maximize its utility [*Bartik*, 1988; *Larson and Gnedenko*, 1999; *McConnell and Rosado*, 2000; *Pattanayak et al*., 2005; *Cook et al.,* 2016b].

The household combines inputs of labor, money, capital, and environmental goods to produce utility-yielding services, conditioned on household preferences (θ). A representative household faces the following utility maximization problem:

$$\max_{T_L,T_C,M,Z} U\big(T_L, Z, S\big(C(T_C, M), W(G)\big);\ \theta\big) \tag{1}$$

$$s.t.\ T = T_W + T_L + T_C + S \tag{2}$$

$$N + wT_W = pM + Z \tag{3}$$

The household values leisure (T_L), a composite consumption good (Z), and health (S), all of which enter directly into the utility function (equation (1)). Health is characterized by the number of sick days, which are a function of the public water supply (W) and coping behaviors (C). The public water supply (W) and coping behaviors (C) are assumed to enter the household's utility function only by promoting health. The public water supply is a function of government policies (G), such as infrastructure provision. If the water supplied by the government is not of adequate quality, quantity, or reliability, households choose a variety of coping behaviors (C) by spending time (T_C) and money on market commodities (M) related to water.

The household faces both a time and a budget constraint. Earned income is limited by the total amount of time available to the household (T), which is spent on work (T_W), leisure (T_L), coping with the limitations of the public water supply system (T_C), and being ill (S) (equation (2)). Spending on the composite consumption good (Z) and market commodities related to water (M), with prices 1 and p, respectively, must equal total income, which is the sum of exogenous income (N), such as returns on capital and remittances, and earned income, which is the product of the hourly wage (w) and the number of hours worked (T_W) (equation (3)).

Households maximize utility by choosing how much time to devote to leisure (T_L), paid labor (T_W) and coping (T_C), how much of the composite good (Z) to consume, and how much to spend on market commodities (M) related to coping with an inadequate water supply. The water supply service level is assumed to be exogenously determined by the government; households cannot choose their current water supply regime [*Cook et al.,* 2016b]. However, if the quality, quantity, or reliability of the services from the public water supply system change ($W(G)$), due for example to new infrastructure investment, the household's optimal choices will also change.

This theoretical framework helps us answer the question, "How much does a household value an improvement in the public water supply system from the status quo $W(G_0)$ to an improved situation $W(G_1)$?" Using duality theory, the utility maximization problem can be transformed into a cost minimization problem to obtain a utility constant willingness to pay (WTP) measure—the change in exogenous income that will compensate for a marginal change in public water supply services [*Pattanayak et al.*, 2005]. This WTP measure, $\frac{\partial \Omega}{\partial W}$, can then be described as the sum of the following three components:

$$\frac{\partial \Omega}{\partial W} = \left[p \frac{\partial \mathrm{M}}{\partial W} + w \frac{\partial \mathrm{T_C}}{\partial W}\right] + w \frac{\partial \mathrm{S}}{\partial W} - \lambda \frac{\partial \mathrm{U}}{\partial S} \frac{\partial \mathrm{S}}{\partial W} \tag{4}$$

Where Ω is the expenditure function in the cost minimization problem, and $\frac{\partial \Omega}{\partial W}$ is the amount of exogenous income, dN, that could be taken away from the household to compensate for the change in utility ∂U as a result of a change (an improvement) in water services ∂W, holding the household at the initial welfare level, U^0. The three terms that form the WTP function are (1) the coping costs in terms of financial expenditures and lost value of time spent coping, (2) lost value of time spent ill, and (3) monetary value of being ill [*Cook et al.,* 2016b]. In this paper, our estimation of coping costs only includes the first term—the financial expenditures on commodities related to water (e.g., purchases of vended water, point-of-use water filters) and the value of time spent coping.

This simple theoretical framework assumes households trade leisure time for work and that the wage rate is the marginal compensation for sacrificing time for money. Therefore, the incremental value of time is indicated by the wage rate [*von Wartburg and Waters*, 2004]. However, there is a rich literature on the value of time that has made many conceptual advances over this simple theoretical construction. This literature shows that there are many situations in which the household's value of time will not approximate its wage rate. From example, if its members cannot control the number of hours they work at the market wage, time savings may not be easily converted to income, and the value of time saved in nonmarket activities will be less than the wage rate [*von Wartburg and Waters*, 2004]. Boardman et al. [2010] review the literature on the value of time spent in different nonwage activities and find that in many cases the values of time are approximately 50% of after-tax wages. Most of these studies have been conducted in industrialized countries and examine tradeoffs households make between money and commuting time. However, there are a few studies from low-income countries that look specifically at the value of time households spend collecting water from outside the home. A discussion of these studies and how our study handles the value of time is carried out in the next section.

Researchers observe the expenditures that households make on "coping strategies" to address the problems caused by unreliable, poor quality public water services. They then use these observational data to obtain a lower bound on household willingness to pay for improved water services. Economists typically interpret estimates of coping costs as a lower bound on households' willingness to pay for environmental services for three reasons. First, households might be willing to pay more for service improvements but the market prices for coping activities are lower than their maximum willingness to pay. Second, there are often additional residual damages. In the case of households coping with unreliable, poor quality water supplies, 24/7 potable water from a private water connection would be an unambiguously better service than the service they can achieve through the coping expenditures. Third, estimates of coping costs typically cannot practically include all of the theoretically plausible coping cost expenditures.

A portion of the coping cost literature focuses on water pollution in the United States [*Abdalla*, 1990; *Collins and Steinback*, 1993; *Laughland et al.*, 1993]. However, our focus is on the literature that applies the theory of coping costs to urban water supply in developing countries. The review of this literature identifies (1) empirical drivers of demand for improved water supply and (2) theoretical refinements in the simple household production function model. Papers in this literature use regression analysis (either ordinary least squares or maximum likelihood estimators) to estimate the association between household coping costs and different covariates. These researchers have faced a common challenge. Heterogeneity in household preferences may introduce systematic errors and bias the estimates of coefficients. Our data give us an opportunity to address this problem in a way that has not been used in the literature previously.

Most of the literature on coping costs and household demand for improved water services uses cross-section observational data. There are only a few field experiments with randomly assigned interventions [*Pattanayak et al.*, 2013; *Jalan and Somanathan*, 2008; *Kremer et al.*, 2011; *Ashraf et al.*, 2010]. Most papers use cross-section, observational data to examine the discrete choices households make to cope with unreliable, poor quality public supplies, and use random utility models to describe household choices [*Madajewicz et al.*, 2007; *Jessoe*, 2013; *Vásquez* 2012; *Katuwal and Bohara*, 2011; *Vásquez et al.*, 2009; *Abrahams et al.*, 2000; *Um et al.*, 2002; *McConnell and Rosado*, 2000; *Larson and Gnedenko*, 1999]. The independence of irrelevant alternatives assumption used in this literature is difficult to defend because some coping methods are arguably close substitutes (boiling, filtering, purchasing bottled water). However, these papers do provide guidance on which explanatory variables can be used to capture technology, tastes, and quantity of water use, which together define the coping cost function [*Pattanayak et al.*, 2005].

For example, the literature shows that perceptions of the water quality, quantity, and reliability of piped water supplies affect coping costs. Abrahams et al. [2000], Larson and Gnedenko [1999], and Um et al. [2002] all find a significant association between coping costs and perceptions of water quality. Madajewicz et al. [2007] find a significant association between coping costs and the provision of water quality information. Vásquez et al. [2009] and Vásquez [2012] find a significant association between coping costs and households' perceived reliability of the piped water supply. Household socioeconomic and demographic characteristics are also commonly included in household models of coping cost decisions, e.g., education, number of children, age, income, and wealth [*Larson and Gnedenko*, 1999; *McConnell and Rosado*, 2000; *Katuwal and Bohara*, 2011; *Vásquez*, 2012].

Different household water sources are also described in these models. Pattanayak et al. [2005] use explanatory variables that describe whether the household has a private water connection, the number of water sources used, and whether the household uses community sources. Jessoe [2013] and Cook et al. [2016b] similarly include explanatory variables to describe a household's primary drinking water source. Vásquez et al. [2009] include variables for storage and bottled water use.

One theoretical concern with the models of coping costs in the literature is that averting behaviors may provide the household utility through different pathways [*Bartik*, 1988; *Cropper and Oates*, 1992]. For example, Abrahams et al. [2000] found that in Athens, Georgia (USA) water quality differences other than health risk (e.g., taste, odor, and appearance) between the public supply and bottled water led to a 12% overestimate of households' willingness to pay for the health benefits of improved water quality. Pattanayak et al. [2005] note that all of the various water sources used by households in Kathmandu have quantity, reliability, and quality dimensions, and that they can only include proxy variables for unit prices, household production, technology, and tastes. Given the numerous water sources used in Kathmandu, they caution that it is not possible to identify household willingness to pay for improvements in different attributes of the public water supply from their data.

In a second study of coping costs in Kathmandu, Katuwal and Bohara [2011] model household coping strategies. Like Pattanayak et al. [2005], they use cross-section observational data on household coping behaviors. Katuwal and Bohara [2011] find that wealth, perception of the quality of water piped connections to the public distribution supply, and exposure to information all have statistically significant effects on coping costs.

Our study makes two contributions to the literature on household coping costs in the municipal water supply sector. First, we describe how coping behaviors and costs have changed over an extended period (from 2001 to 2014) in a city whose inhabitants have experienced rapid population growth and political instability, in addition to a deteriorating water supply infrastructure. By revisiting the same households interviewed in 2001, this study describes how the economic costs experienced by households have changed as a result of a lack of investment in the municipal water supply infrastructure at the same time that private investment in the water vending industry and wells has increased.

Second, our research design allows us to examine population heterogeneity in taste parameters. Because we have data on the same households in 2001 and 2014, we can use differences in household coping cost estimates as the dependent variable and thus control for time invariant household-level unobservables, such as taste preferences that have not changed from 2001 to 2014. This strengthens the validity of our analysis of the determinants of coping behaviors and costs.

2.4 Coping Costs Modeling Strategy and Calculation

2.4.1 Modeling Strategy

Coping cost functions, similar to the cost functions of firms, depend on unit prices of inputs and outputs, conditional on production technology and household preferences or tastes [*Pattanayak et al.*, 2005]. Proxy variables are used to capture time-varying tastes, technology, and the quality of water used by the household. We replicate, with some modifications, the analysis done by Pattanayak et al. [2005] with the 2001 Kathmandu coping cost data, and we estimate a linear regression model relating total coping costs ($copingcosts_{it}$) to the set of observables in which we are interested (household demographic characteristics, water source characteristics, quality perceptions, and policy preferences). However, unlike Pattanayak et al. [2005], we are able to use two cross-sectional data sets. Additionally, we add to the model the respondent's gender, reliability of the private water connection as measured by hours of service, having a private well, and quality perceptions, as suggested by the more recent coping cost literature. Equation (5) illustrates our coping cost model, which uses differences between variables in 2014 and 2001 to eliminate unobserved factors that do not change over time:

$$\begin{aligned} copingcosts_{i2014} - copingcosts_{i2001} \\ = \beta_1(hh\_char_{i2014} - hh\_char_{i2001}) + \beta_2(water\_char_{i2014} \\ - water\_char_{i2001}) + \beta_3(perceived\_quality\_wet_{i2014} \\ - perceived\_quality\_wet_{i2001}) + \beta_4(perceived\_quality\_dry_{i2014} \\ - perceived\_quality\_dry_{i2001}) + \beta_5(policy\_pref_{i2014} - policy\_pref_{i2001}) \\ + u_{i2014} - u_{i2001} \end{aligned} \tag{5}$$

Important household demographic characteristics (vector hh_char_{it}) include income, education, gender, and number of children. Water source characteristics (vector $water\_char_{it}$) include having a private water connection, having a private well, having both a private water connection and a private well, reliability of the private water connection, and number of water sources used. Quality perceptions (vector $perceived\_quality_{it}$) are respondent ratings of taste, dirtiness, health risks, and reliability of piped water in year t (t = 2001 or t = 2014) in both the wet and dry seasons. Policy preferences ($policy\_pref_{it}$) describe the respondent's belief about whether water issues were the most serious environmental policy problems faced by the residents of Kathmandu Valley. Stochastic components (u_{it}) capture the idiosyncratic effects of unobserved factors.

2.4.2 Calculation of Coping Costs

We disaggregate coping costs into the costs associated with five coping behaviors: (1) collection time, (2) private well construction and operation, (3) water storage and rainwater collection, (4) in-house water treatment, and (5) monetary payments to water vendors and other informal suppliers. Our categorization and calculation of coping cost components differs from the 2001 construction by Pattanayak et al. [2005]. Rainwater collection system costs are separated from private well construction and operation and placed with water storage because these systems often share equipment. The lifespan of all equipment has been changed to be 20 years, instead of 15 years for wells and 30 years for rainwater systems and storage equipment. We next describe the calculation of the costs of each of these five components. We do not include estimates of costs of illness because we are not able to accurately attribute medical expenditures to poor water and sanitation conditions.

2.4.2.1 Collection Costs (Time Spent)

In our household interviews, we collected data to estimate the time households spend collecting water from outside the home. Household members spend time walking to and from water sources outside the home, as well as waiting at a source. Our households report an average of 1.2 water collectors per household. Six hundred and ninety-four households have only one collector, 149 have two, and three households have three water collectors.

We estimate the costs of time spent collecting water by multiplying the self-reported amount of time by an assumed shadow price of time. Some might argue that time savings from not having to collect water would only have an economic value to households if they were devoted to income-generating activities. However, there are numerous reasons why households would be willing to pay for time savings that could result from improved water services besides devoting the time savings to paid labor, e.g., increased leisure, child care, food preparation, as well as schooling and preventative health activities.

We did not undertake a separate study to estimate the shadow price of time in Kathmandu. Rather, we look to other studies in the literature where researchers estimate the economic value households place on time savings from not having to collect water. This benefit transfer approach (i.e., of transferring estimates of the shadow price of time from other study sites to the policy study site of interest—in our case Kathmandu) is common in economic analyses that need to estimate the economic value of nonmarket outcomes such as the time spent collecting water [*Boardman et al.,* 2010].

Cook et al. [2016a] provide a comprehensive overview of estimates of the value of travel time in low-income countries. They begin with an overview of studies from the transportation sector, which find value of time estimates ranging from 18–86% of wages. Cook et al. [2016a] also review three papers that value time within the context of water collection. Whittington et al. [1990] find a value of 100% of unskilled wages in a small Kenyan town, even though there was no evidence that these time savings would be devoted to paid labor. Asthana [1997] find a value of 35% of the unskilled wage rate in rural India, and Kremer et al. [2011] estimate a value of travel time of only 7% of the unskilled wage rate in rural Kenya. Cook et al. [2016a] themselves use a stated preference choice experiment to estimate a household-specific value of time spent collecting water. Their results from a random-parameters logit model suggest an average value of time spent collecting water of 18 Ksh/h (US$0.21 per hour), approximately 50% of the market wage rate. Using a latent class model, these authors find considerable heterogeneity in the value of time spent collecting water across four different groups of households. The first group (about one third of respondents) values time very highly (49 Ksh/h). A second, poorer group values time hardly at all (less than 1 Ksh/h). The third and fourth groups value time at approximately 9 Ksh/h.

In another study, DeVoto et al. [2012] find that in Tangiers, Morocco, households' willingness to pay for the time savings and convenience associated with private water connections is high compared to public taps but not because a private connection improves health or opportunities for paid labor. Instead, these authors find that households are willing to pay for a private water connection because it increases the time available for leisure and reduces both inter- and intrahousehold conflicts over water.

These studies provide strong evidence that many household place a positive value on the time spent collecting water. None of these estimates of the value of time rely upon evidence that households would devote time savings from not having to collect water to paid labor or income generating activities. In fact, DeVoto et al. [2012] show that households place a monetary value of time savings devoted to non-income producing activities, including leisure. Based on these results, we believe that it is reasonable to assume that many households in Kathmandu likely place a monetary value on the time they spend collecting water from outside the home, even without evidence that these time savings would be allocated to paid labor or other income-generating activities. For our estimates of coping costs in Kathmandu, we rely on Cook et al.'s [2016a] findings from Meru, Kenya.

As in Pattanayak et al. [2005], our 2014 estimates of the value of time spent collecting water are household-specific and distinguish between households with domestic servants and those without. For households without domestic servants, we assume a value of time equal to 50% of the average hourly wage of employed individuals in the household. For households with domestic servants, the value of time spent collecting water is assumed to be the average wage rate of the lowest paid individuals in the neighborhood where the household is located. For respondents that did not report an income (N = 57), the value of time spent collecting water is assumed to 50% of the median household mean hourly wage in the neighborhood. (Other missing variables were dealt with similarly.) The average hourly wage was estimated from self-reported monthly income assuming a six day work week and 10 h working day. The average hourly wage for households in the 2014 sample was 89 NPR (median 78 NPR), about US$0.93 (based on a 2014 exchange rate of 95 NPR to US$1).

We emphasize that these are assumptions about the value of time spent collecting water in Kathmandu and are not based on any empirical data from our household survey. To show the sensitivity of our coping cost estimates to these assumptions about the value of time spent collecting water, we also present estimates of household coping costs in both 2001 and 2014 assuming that the value of time spent collecting water is zero (Table 4). These coping cost estimates that assume a zero value of time are best viewed as a lower bound of what households are willing to pay for improved services. Respondents reported the distance from their home to a water source in either meters (m) or minutes (min). For those who report the distance in meters, we assumed a walking speed of 80 m/min to estimate the time spent walking to the source. For respondents that did not report time or distance to a source, the median distance to the same type of source of other households in the neighborhood was assumed. The total time spent for one trip from the home to a water source was the round-trip walking time plus the self-reported queuing time at the water source.

2.4.2.2 Private Wells and Pumping

The monthly household costs of private wells consist of capital and operation and maintenance expenses. The annual capital costs were estimated by multiplying the value of the capital asset (as estimated by the respondent to be the present day replacement value of the capital good) by a capital recovery factor based on the life of the asset and a real discount rate of 10% (private wells and electric pumps were both assumed to have a lifespan of 20). Operation and maintenance costs include self-reported, ongoing minor repairs and electricity use. Households without private wells also reported owning pumps. These were often used to extract water directly from the piped water system. Their capital and operation and maintenance expenses are also calculated.

2.4.2.3 In-House Water Treatment Costs

Households incur water treatment costs for both boiling and filtering. Filtering may entail additional household expenditures for equipment; boiling typically does not. We estimated the monthly capital costs for the water filters using the same approach as for private wells and rainwater collections systems. Annual operation and maintenance (O&M) costs are based on self-reported monetary expenditures.

The costs of boiling water are based on estimates from Tiwari [2000]. Households in our 2001 and 2014 surveys were asked the frequency with which they boiled their drinking and cooking water (e.g. “almost always”, “occasionally”, “rarely or never”), and the monthly household costs of boiling are adjusted depending on the respondent's answer. Using the International Monetary Fund's inflation index for average consumer prices in Nepal [*International Monetary Fund*, 2015], Tiwari's 1998 estimate for the costs of boiling water (95 NPR/month) is equivalent to 282 NPR in 2014. Households that answered "almost always" are assumed to incur boiling costs of 282 NPR/month, and households that answered "occasionally" are assumed to incur boiling costs of 141 NPR/month. There were no households in our sample that reported that they "rarely or never" boiled their drinking water.

2.4.2.4 Household Storage and Rainwater Harvesting Systems

Households can purchase overhead or underground storage tanks. Monthly capital costs of water storage assets are calculated based on reported replacement costs, a 20-year economic life of the facilities, and a 10% real interest rate. If a storage tank is shared amongst households, only a proportion of the total cost was assigned to the respondent's household.

Rainwater harvesting systems are centered around a water storage container, such as a barrel, bucket, or tank, and are therefore included in this section. The monthly capital costs of rainwater collection systems are again calculated assuming a 20-year economic life and a 10% real interest rate.

2.4.2.5 Monetary Payments to Water Vendors and Other Suppliers

To calculate total household coping costs, we added the monetary payments the household made to private water tankers, bottled water vendors, and public utility tankers, to the estimated monthly costs it incurred for the other four coping cost components described above. Monetary payments made to neighbors are also included, as well as any payments made to access water from stone taps. Payments households made to obtain water from public taps and wells are not included in the coping costs but are categorized as public costs paid by households, similar to household water bill payments. At some water sources outside the home, households made a monetary payment to obtain water. The latter are included in the coping cost component ‘‘monetary payments to water vendors and informal suppliers'' (not in the estimates of the coping costs associated with collection time).

In Kathmandu households may pay for water from public taps in several ways. In some cases, KUKL provides a ''public'' tap that is shared by a designated group of households. KUKL provides these households a fixed monthly water bill regardless of the volume of water used. This water bill is then shared by these households. There are also situations where a community association constructs a storage tank and fills it with water from public taps owned by KUKL or with water from the ancient system of stone taps. In this case the community association may collect a fixed monthly fee from households to pay for management expenses. The community association may charge a minimal fee for maintenance and management of the storage facility. Other community associations work together to build a community storage tank, and purchase water from tanker truck vendors to fill the storage tank. In this case, households are typically charged for each bucket they collect. Again, we distinguish between payments households make to the public utility (KUKL) for both private connections and use of public taps, as well as payments to water vendors and informal sup- pliers. The former are not included in the estimates of coping costs, but instead are reported separately.

2.4.3. Summary

As described above, we include annualized capital costs for household investments in private wells and pumps, water storage, and in-house water treatment systems in our estimates of household coping costs. One common theoretical formulation of the coping cost model assumes that there are no significant adjustment costs associated with reducing the level of investment in defensive measures [*Bartik*, 1988] and that household coping behaviors do not include any large, discrete capital expenditures to avert damages. If coping strategies do not involve capital expenditures, they can be easily stopped, i.e., households have low adjustment costs. For example, a household purchasing water from vendors makes periodic, regular expenditures to cope with unreliable, poor quality water services, but these expenditures can be quickly reversed if a new improved piped water service is installed. In this case the coping cost expenditures represent potential cost savings and will be a theoretically-defensible lower bound on the household's willingness to pay for the improved piped water system.

On the other hand, some authors incorporate capital expenditures in their estimates of coping costs [*Abdalla*, 1990; *Cook et al.*, 2016b; *Pattanayak et al.*, 2005]. In Kathmandu, many households incur capital costs to ameliorate the consequences of unreliable, poor quality public supplies. These capital costs are not quickly reversible (i.e., have higher adjustment costs), and they are best characterized as sunk costs in the short term. Once such capital investments have been made, the short-run marginal costs of using them may be low. Therefore, for a household that has already made such investments, the short-run cost savings of switching to a new improved public system with 24/7 potable water supply will be much less than, for example, a household relying largely on bottled water vendors.

Because our calculations include annualized capital costs, it is not possible to confidently interpret them as lower bound estimates of households' willingness to pay, at least in the short run. In particular, households with the complete suite of private capital investments (private well and pumping systems, storage, and in-house water treatment systems) would experience relatively modest financial cost savings in the short run from switching all their water use to an improved (24/7) potable private water connection.

Because our estimates of coping costs may not reflect potential cost savings in the short run, they cannot be interpreted as lower bound estimates of household willingness to pay. However, we choose to include annualized capital costs in our estimates of coping costs for two reasons. First, by including capital costs, our coping costs estimates better illustrate long-run demand for improved public water supplies. Households' capital investments in private wells and pumps, storage, and in-house water treatment systems will not last indefinitely. Households will certainly achieve substantial cost savings and better service from switching to an improved public system after the MWSP is complete rather than reinvesting capital in private coping solutions.

Second, households with private wells may face the prospect of additional capital costs sooner than expected. Groundwater levels in Kathmandu have been falling and declines in well yields have become common [*Pandey et al.*, 2012]. Some households with private wells may soon find that they can no longer reach the groundwater and will need to dig (drill) a deeper well, incurring additional capital costs.

2.5 Description of Study Site, Fieldwork, Sample Households, Existing Water Collection Practices, and Perceptions

2.5.1 Fieldwork

The 2001 household survey was designed to obtain a representative sample of 1500 households in the five municipalities of Kathmandu Valley: Kathmandu, Lalitpur, Bhaktapur, Kirtipur, and Madhyapur. Households were selected using a multistage cluster sampling procedure. In Nepal, the ward is the lowest level administrative unit. There are nine wards in a Village Development Committee (VDC) and more than nine wards in municipalities (the precise number depends on the size of the population). In the first stage of the multistage cluster sampling procedure, we followed the common practice among survey researchers in Nepal and considered the ward as the primary sampling unit (PSU). For example, the Nepal Demographic and Health Survey (DHS), Nepal Living Standard Measurement Survey (LSMS), and Nepal Labor Force Survey (NLFS) all used the ward as the PSU. We selected wards based on a population-proportionate-to-size procedure, using the number of households in each ward. This ensured that in the first stage households had an equal probability of being included in the sample [*Babbie*, 1990].

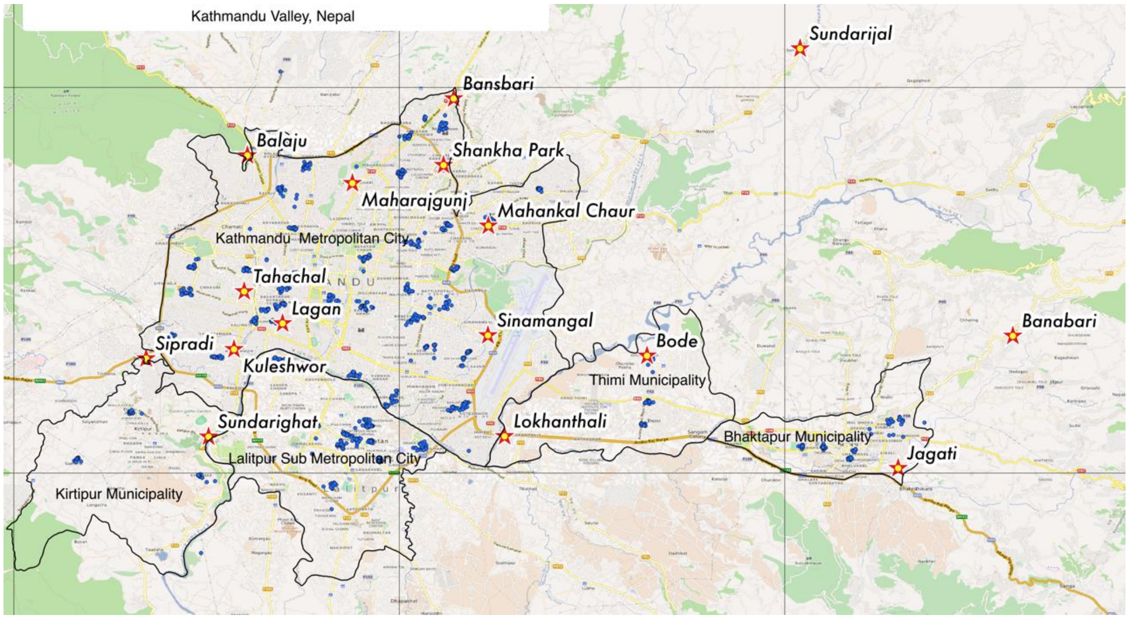
In this first stage, wards were located using aerial maps provided by the Central Bureau of Statistics for the 1996/97 World Bank Living Standard Measurement Survey for Kathmandu. In three of the five municipalities in the Kathmandu Valley (Kathmandu, Lalitpur, and Bhaktapur), a previously conducted complete enumeration of all households was used to estimate the population of the wards [*SILT Consultants and Development Research and Training Center*, 1999]. In Kirtipur and Madhyapur, the 1991 population census was used to approximate population size.

In the second stage, we subdivided each ward selected in the first stage into groups of 25 households (termed a "cluster"). Large wards thus had more clusters than smaller wards. Field supervisors, working with enumerators, created maps that identified these clusters of 25 households in each selected ward. The required number of clusters to be selected in the second stage was determined by the total sample size, and clusters were selected randomly.

In the third (final) stage, if a cluster was selected for inclusion in the sample, then respondents from all 25 households in that cluster were interviewed. The final sample consisted of 60 clusters of 25 households each covering all five municipalities in the Kathmandu Valley (1500 total households).

In the 2014 resurvey of the 2001 households, if we were unable to locate the original household, a nearby household was selected for an interview. If the household head from a 2001 sample household was missing, the present head or a responsible member of the house was interviewed instead. In total we were able to locate and reinterview 927 of the 1500 households from the 2001 survey. In the 2014 survey, there are thus 573 replacement households. Figure 1 shows the location of the sample households in the 2014 survey in the Kathmandu Valley, both the matched and replacement households.

Figure 2.1. Location of household clusters in Kathmandu Valley – 2014 Survey



Although the 2001 households were a representative sample of the population in the five municipalities in Kathmandu Valley, the sample from the 2014 resurvey is not. Households that migrated to Kathmandu over the period from 2001 to 2014 are not part of our 2014 sample unless they happened to be included as a replacement household. For all the descriptive analyses presented in the paper, we compare the 2001 households with all of the 2014 households (i.e., including both the matched and replacement households). However, replacement households were excluded in the regression analysis in order to control for unobserved household taste parameters.

Fieldwork was conducted over a three-month period from August to October 2014 (the rainy season in Kathmandu). Nineteen experienced enumerators were hired and trained. They conducted the interviews under the supervision of senior field supervisors from the Institute of Population and Development Studies, in Kathmandu, Nepal.

2.5.2 Profile of Sample Households

Table 1 presents the demographic and socioeconomic characteristics of the overall 2001 and 2014 samples. Table 1 also presents a simple typology of four types of households based on their use of the two main water sources in Kathmandu (for 2014, percentage of sample noted in parentheses): (1) no private water connection and no private well (5% of the sample households); (2) private water connection and no private well (40% of the sample households); (3) no private water connection and private well (6% of the sample households); and (4) private water connection and private well (49% of the sample households). As shown, household heads are naturally older in 2014, increasing from 46 to 57 years of age. Years of education have also increased, from 7 years of education for the head of household in 2001 to 8 years of education in 2014. The percentage of male respondents decreased from 63% to 52%; the percentage of respondents who are married decreased from 85% to 78%. Household sizes are smaller in 2014, reflecting both children leaving home and the demographic transition to smaller families. In 2001, the average household size was eight; in 2014, it was five. The percentage of households with domestic servants decreased. In both 2001 and 2014 home ownership, electricity coverage, and phone coverage (both landlines and mobile phones) are very high. Sewer connections increased from 71% to 90%. Monthly electricity bills decreased in real terms, but monthly phone bills increased.

Table 2.1. Demographic and socioeconomic profile of sample households, by type (2001, 2014)

	2001					2014				
	No PWC, no private well	No PWC, private well	PWC, no private well	PWC, private well	Overall	No PWC, no private well	No PWC, private well	PWC, no private well	PWC, private well	Overall
Number of households	334	166	710	290	1,500	68	94	600	738	1,500
Percent of total households	22%	11%	47%	19%	100%	5%	6%	40%	49%	100%
Age of household head, years	44	43	48	49	46	53	52	57	57	57
Education of household head, years	4	8	8	10	7	4	6	7	9	8
Percentage of respondents who are male	63%	59%	64%	63%	63%	44%	35%	56%	53%	52%
Percentage of respondents who are married	87%	88%	84%	86%	85%	75%	82%	79%	77%	78%
Household size (number of people)	7.8	7.4	8.0	8.3	7.9	5.1	4.7	5.1	5.1	5.1
Monthly household income, 2014 NPR (thousands, adjusted)	21	41	44	62	42	36	40	48	68	57
Property value, 2014 NPR (millions, adjusted)	1.7	7.7	7.4	7.6	6.1	3.5	5.3	7.5	15.1	11.0
Percentage of respondents who are homeowners	92%	88%	85%	88%	88%	79%	56%	93%	96%	92%
Percentage of households that have domestic servant(s)	2%	15%	12%	19%	11%	0%	7%	2%	9%	6%
Percentage of households that have electricity	93%	98%	100%	100%	98%	100%	98%	100%	100%	100%
Monthly electricity bill, 2014 NPR (adjusted)	546	1,448	1,331	2,024	1,314	455	790	679	1,129	897
Number of cellphones						2.9	3.0	3.1	3.3	3.2
Monthly phone bill, 2014 NPR (adjusted)	115	1,100	959	1,579	912	734	948	1,136	1,506	1,288
Percentage of households that have a sewer connection	47%	47%	84%	80%	71%	76%	61%	93%	92%	90%
Amount of water collected (L/capita/day, dry season)	12.4	3.6	6.2	3.6	6.8	35	69	45	94	70
Amount of water collected (L/capita/day, wet season)	12.9	4.5	7.1	2.8	7.2	34	74	58	114	85
Number of sources used	1.7	1.9	2.0	2.5	2.0	2.7	2.3	2.6	2.7	2.6

Household incomes are measured as the estimated total monthly cash income of all wage earners and self-employed individuals in the household and other possible sources: rental income, pension and/or government cash transfers, and other income from interest, dividends, capital gains, etc. We do not include subsistence agriculture production or barter transactions. Real incomes of sample households have increased by 35% over the 13-year period, from 42,000 NPR per month (adjusted to 2014 NPR) to 57,000 NPR; and the estimated average real market value of the households' dwellings have nearly doubled—from 6.1 million NPR to 11 million NPR.

2.5.3 Existing Water Collection Practices and Perceptions

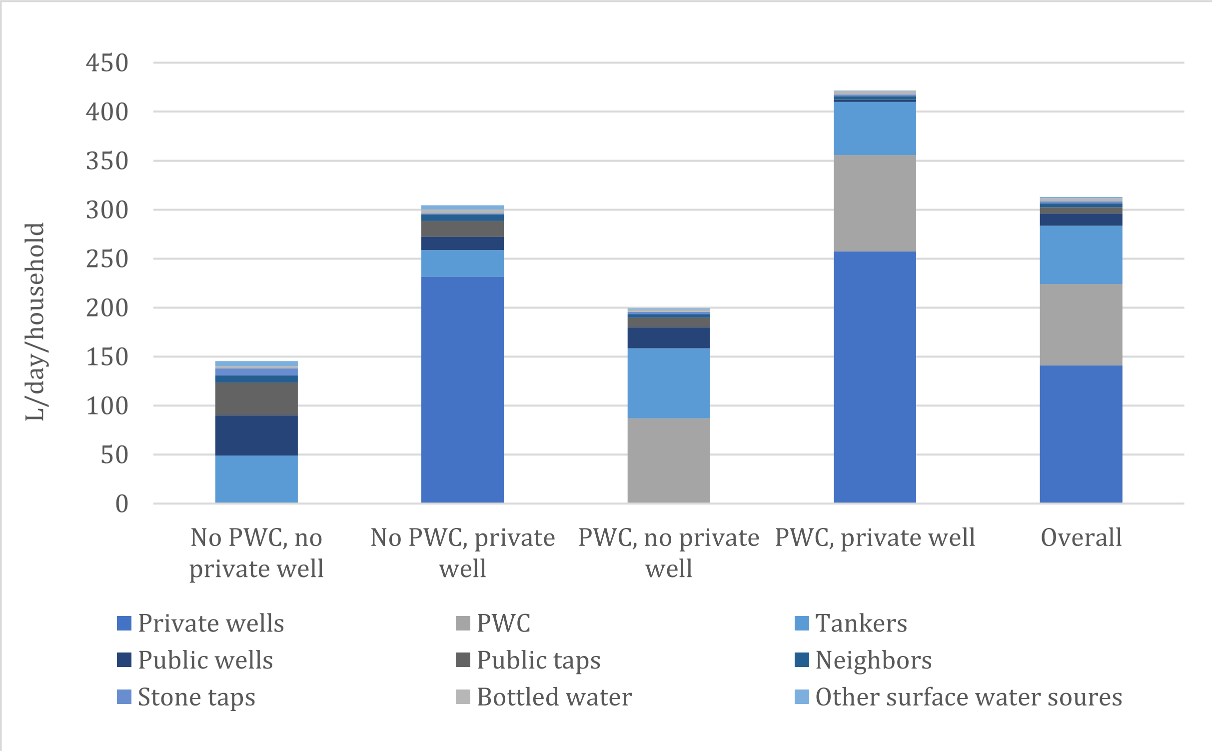
Focusing on our entire 2014 sample (i.e., with replacement), we find that households reported that they have access to an average of 4.1 water sources (median 4, range 1–8 sources). They actually used an average of 2.6 sources (median 3, range 1–6 sources), with 85% of households using two or more sources. The two water sources most used by households in 2014 were private water connections (PWCs) and private wells. Overall, approximately 30% of household water supply volume used by sample households comes from private connections, 29% from private wells, 20% from tankers, 8% from public wells, 6% from public taps, and the rest (7%) from neighbors, bottled water (20 L jars), stone taps, and surface water. On average, sample households self-supplied or purchased 85 liters per capita per day (lpcd) in the rainy season and 69 lpcd in the dry season. The median amount self-supplied or purchased in the rainy season was 48 lpcd and 41 lpcd in the dry season. (Note that these water use figures are based on respondents' recall of how much water they used per day from each source in both the rainy and dry seasons. We do not consider these to be precise estimates of household water use due to the difficulties many respondents are likely to have recalling the amounts of water collected, especially from private connections and private wells.)

Compared to 2001, the number of households with neither a PWC nor a private well has decreased from 22% to 5% of the sample, while the percentage of households with both a PWC and private well has increased from 19% to 49%. In 2014, households with neither a PWC nor a private well use the least amount of water (35 lpcd in the dry season). Households with only a PWC use less water (45 lpcd, dry season) than do households with only a private well (69 lpcd, dry season). Households with both a PWC and private well use the most water (94 lpcd, dry season). These amounts cannot be compared with 2001 data because estimates of the amounts of water from PWC and private wells were not collected in the 2001 survey. The World Health Organization suggests a minimum safe water requirement of 20 lpcd for basic needs (cooking and drinking) in emergency situations, and 70 lpcd for washing, cleaning, laundry, growing food, and sanitation [*Reed and Reed*, 2013]. Even though the average water consumption levels in Kathmandu are above these WHO minimums, the quantity of water many households acquire is below these amounts and the quantity of water obtained is neither reliable nor of good quality. Additionally, the water use of 16% of our sample falls below even the minimum safe water requirement during the dry season.

Households that have both a PWC and a private well tend to be richer, with a monthly income that is nearly double that of the other groups. They also live in houses with much higher market values, have higher electricity and phone bills, and are more likely to have domestic servants. These patterns are similar to those in 2001, but the socioeconomic disparities were less extreme between the four types of households in 2014.

Figure 2 shows the average amount of water used by household type and how much water comes from each source during the dry season. The proportions are calculated as a population average of households in each group. Households with neither a PWC nor a private well collect their water from a variety of sources, mainly tankers, public wells, and public taps. Those with a PWC but no private well obtain most of their water from PWCs, supplementing their water supply with water tankers and public wells. Households with a private well but no PWC obtain most of their household water from their private well. Households with both private wells and PWC often obtain additional water from tankers. Across all four types of households, the quantity of water purchased from tankers is similar, ranging from 36 to 48 lpcd in 2014 and 7 to 61 lpcd in 2001 (see Table 2). Households with a private well (both those with and without a PWC) are using substantially more water than households without a private well.

Figure 2.2. Quantity of water collected by source and household type in the dry season (2014)



Households' water supply situation and their responses to the growing water shortage have changed from 2001 to 2014. The number of households in the matched sample that had private connections and private wells grew significantly from 2001 to 2014. Over a third of the households that did not have connections in 2001 managed to get connected by 2014 (138 out of 338 households). However, fourteen percent of households with connections in 2001 stopped using their private water connection in 2014 (84 out of 589 households). Twenty-three percent of households that had a private well in 2001 stopped using their well in 2014 (57 out of 249 households). Twenty-four percent of households that did not have a private well in 2001 managed to obtain one by 2014 (163 out of 678 households). Reasons why households would stop using their PWCs and private wells could be due to a lack of water, increased contamination, or both.

Table 2.2. Amount collected by type and year (L/capita/day, dry season)

	2001										2014									
	No PWC, no private well		No PWC, private well		PWC, no private well		PWC, private well		Total		No PWC, no private well		No PWC, private well		PWC, no private well		PWC, private well		Total	
	L	N	L	N	L	N	L	N	L	N	L	N	L	N	L	N	L	N	L	N
PWC															29	416	29	572	29	988
Public taps	6	156	5	14	5	102	4	12	6	284	12	39	11	29	14	99	7	6	13	173
Public wells	8	131	3	4	6	160	4	7	7	302	18	38	20	12	16	174	19	18	17	242
Neighbors	7	104	4	81	4	230	3	70	4	485	38	3	17	11	8	62	10	57	10	133
Private well													70	70			77	549	76	619
Tankers	54	6	7	11	61	22	48	14	46	53	37	24	48	14	36	260	45	190	40	488
Stone taps	10	54	5	10	7	97	4	15	8	176	21	6	5	5	17	17	21	14	17	42
Other surface water sources	7	73	4	9	9	7	17	1	7	90	11	6	11	7	19	8	8	3	13	24
Bottled water	0	1	1	6	1	17	2	5	1	29	2	17	2	42	2	169	2	301	2	529
Total	12	334	4	166	6	710	4	290	7	1,500	35	68	69	94	45	600	94	738	70	1,500

Table 2.3. Respondent's perceptions of water quality from available sources, by year and season (percentages of respondents that have a highly negative perception)

Source/Quality	Poor taste				Very dirty				Serious health risks				Unreliable			
	Wet		Dry		Wet		Dry		Wet		Dry		Wet		Dry	
	2001	2014	2001	2014	2001	2014	2001	2014	2001	2014	2001	2014	2001	2014	2001	2014
Private water connection	53	33	11	24	17	7	3	5	25	33	6	32	10	8	38	24
Public taps	42	13	5	5	11	2	1	2	19	9	4	8	6	1	18	13
Public wells	28	30	13	31	7	3	3	5	12	23	6	21	3	1	4	27
Neighbors that give water away	36	13	9	12	14	1	4	1	16	14	5	13	14	9	35	24
Private well	40	37	31	37	12	2	10	2	25	44	20	44	2	0	4	8
Vendors/tank	16	18	6	16	5	1	5	0	13	16	11	15	20	5	20	9
Stone spouts	6	5	2	4	1	2	1	1	2	4	1	5	2	5	6	33
Other surface water sources (river/stream/lakes)	26	23	21	17	8	2	7	0	5	22	3	18	7	2	9	28
Rainwater	32	45	23		5	2	5		12	28	11		70	71	76	
Bottle mineral water									9	1	9	1				
Jar water (20 liter)										1		1				

We asked households to estimate how much water from each source was required for each household task (drinking, cooking, bathing, washing and cleaning). Sample respondents report that most water sources are used for more than one task. On average, households report 1.35 to 1.46 sources used for each task. Piped water and public taps are used mostly for cooking and drinking; public wells are used mostly for bathing and washing. Water from neighbors is most commonly used for cooking; private wells and tanker water for bathing and washing. Ninety-nine percent of households that use 20 L jars report that it is used for drinking. A typical household with the median household income (42,000 NPR), median water consumption per capita (40 lpcd), and median number of water sources used (three), uses most of the water from their PWC for drinking and some for cooking. This household also uses vended water from tankers for bathing, washing, and other purposes. Finally, they also purchase 20 L jars for drinking.

Table 3 presents households' perceptions of the quality and reliability of water from different sources for the 2001 and 2014 household surveys. For the rainy season, households interviewed in 2014 report that quality (taste and dirtiness) and reliability of water from different sources have generally improved compared to 2001. However, more households report negative perceptions of health risks for PWCs, public wells, private wells, surface waters, and rainwater. On the other hand, the quality (taste, dirtiness, health risks) and reliability in the dry season have declined compared to 2001. However, fewer households report negative perceptions about the dirtiness of water from neighbors, private wells, and vendors. There are also decreases in the percentages of households reporting highly negative perceptions about the reliability of water from PWCs, public taps, neighbors, and vendors.

We expected the quality and reliability of most water sources to decline from 2001 to 2014 due to lack of public sector investment and increased population and economic pressure on existing supplies. The link between deteriorating quantity and quality of water from the piped distribution arises because of the negative pressure in the intermittent piped system, allowing contaminated groundwater to enter the distribution systems. Of course, households interviewed in 2014 do not report that the quality (taste, dirtiness) and reliability of the main water sources (private connections, private wells, and vendors) are good, just that they are not as bad as in 2001. We do find increases in percentages of households reporting perceived health risks from private connections, private wells, and vendors.

Another big change is that households are using much more water from tanker truck and bottled water vendors in 2014 than in 2001. In 2001, 53 sample households purchased water from tankers, compared to 505 households in 2014. There was also a large increase in the purchase of bottled water. In 2001, 30 sample households purchased bottled water compared to 529 households in 2014.

2.6 Household Coping Costs (2001 Versus 2014)

In this section we describe our main findings. We first present our overall 2014 estimates of household coping costs for the entire sample. Then we discuss the 2014 coping costs and their components using our household typology described in the last section. With this baseline we then explore how coping costs have changed from 2001 to 2014. Next, we examine differences in coping costs between households with different income levels. Finally, we compare household coping costs to public costs paid by taxpayers/donors and to the costs paid by households for public water supplies (i.e., water bills and payments for water from other public sources).

Table 2.4. Coping costs, by types and year (2014 NPR)

		2001		2014		Difference	
		NPR	N	NPR	N	NPR	N
No PWC, no private well	Collecting	388	332	902	64	553	67
	Pumping	--	0	66	14	45	17
	Treating	125	89	109	33	64	34
	Storing	65	82	162	47	135	50
	Buying	543	10	392	42	392	42
	Total	451	334	1,269	68	929	68
	Total (without collecting)	66	334	420	68	384	68
No PWC, private well	Collecting	401	102	1,215	52	465	75
	Pumping	117	166	456	76	348	82
	Treating	253	116	116	50	-56	67
	Storing	201	90	422	63	246	76
	Buying	2,533	11	475	60	416	62
	Total	816	166	1,687	94	1,108	94
	Total (without collecting)	570	166	1,016	94	736	94
PWC, no private well	Collecting	348	442	404	252	-112	512
	Pumping	--	0	93	415	80	428
	Treating	152	488	136	383	26	462
	Storing	142	446	267	554	206	570
	Buying	1,325	20	493	412	447	418
	Total	448	710	906	600	488	600
	Total (without collecting)	231	710	737	600	584	600
PWC, private well	Collecting	516	96	364	65	-356	396
	Pumping	95	290	369	709	315	716
	Treating	175	256	191	599	8	709
	Storing	239	229	488	704	337	717
	Buying	825	6	623	444	510	452
	Total	626	290	1,382	738	762	738
	Total (without collecting)	455	290	1,350	738	954	738
Overall	Collecting	384	972	569	433	-121	1,050
	Pumping	103	456	277	1,214	233	1,243
	Treating	168	949	165	1,065	13	1,272
	Storing	167	847	384	1,368	272	1,413
	Buying	1,378	47	547	958	472	974
	Total	524	1,500	1,206	1,500	682	1,500
	Total (without collecting)	275	1,500	1,041	1,500	766	1,500

Table 4 presents our 2014 estimates of household coping costs and our recalculated 2001 estimates. Estimates for 2001 were recalculated to allow for consistent comparison between 2001 and 2014 as described in section 4. Table 4 breaks down the coping costs by coping method, type of household (regarding PWC and private well), and by year for the entire sample. For each average cost estimate, only the expenditures of households that use the coping method are included, which is why the sample size varies and the columns cannot be summed. The average household incurs costs of 1206 NPR (US$12) per month coping with the poor quality, unreliable public water supply system. Most households incur costs associated with storing (384 NPR, N=1368), private wells and pumping (277 NPR, N=1214), treating (165 NPR, N=1065), and purchasing (547 NPR, N=958). Some households also incur time costs associated with collecting water (569 NPR, N=433).

In 2014, households without a private water connection and without a private well spent 1269 NPR on coping costs. Households with only a private water connection spent only 906 NPR per month. Households with only a private well spent the most—1687 NPR per month. Households with both a private water connection and a private well spent 1382 NPR per month.

For the 68 households without either a PWC or a private well, almost all households (N=64) incur most of their coping costs from collection costs (averaging 902 NPR per month). Forty-two households in this group purchase water and their purchasing costs are substantial (392 NPR). Pumping, treating, and storing costs are smaller, with less than half of the households using these coping methods.

The 94 households without a PWC but with a private well incur the highest coping costs, with much of that coming from collection costs. The average household collection cost for the 52 households in this group with positive collection costs was 1215 NPR. Many households in this group also incur pumping costs (456 NPR, N=76) and storing costs (422 NPR, N=63). These households spend a similar amount buying (475 NPR, N=60) and treating water (116 NPR, N=50).

For the 600 households with a PWC but no private well, most incur costs storing (267 NPR, N=554), buying (493 NPR, N=412), and pumping (93 NPR, N=415). Over half also participate in treating (136 NPR, N=383) and collecting (404 NPR, N=252). Collecting costs are less than those of an average household without a PWC.

The 738 households with both a PWC and private well incur large costs pumping (369 NPR, N=709) storing (488 NPR, N=704), and purchasing (623 NPR, N=444). The costs of treating are smaller (191 NPR, N=599). Only a small portion of these households incurs costs collecting water (364 NPR, N=65).

Figure 3 summarizes the composition of coping costs for households in each of the four groups. It shows the average cost for a household for each of the five coping strategies. Because not all households use all coping methods, the composition of coping costs for each of the four groups should not be interpreted as representative of an average household. We see that unconnected households incur higher coping costs than connected households, which is primarily due to greater time spent collecting water. Additionally, households with private wells incur higher coping costs because they spend more on building and operating pumps and wells. Storage costs are highest for households with both a PWC and a private well, slightly less for households with only a PWC or only a private well, and the least for households without either a private well or a private connection. Purchases from water vendors are similar across all four household types. Treatment costs for households with both a PWC and a private well are higher than those for the other three household types.

Figure 2.3. Composition of coping costs, by household type (2014)

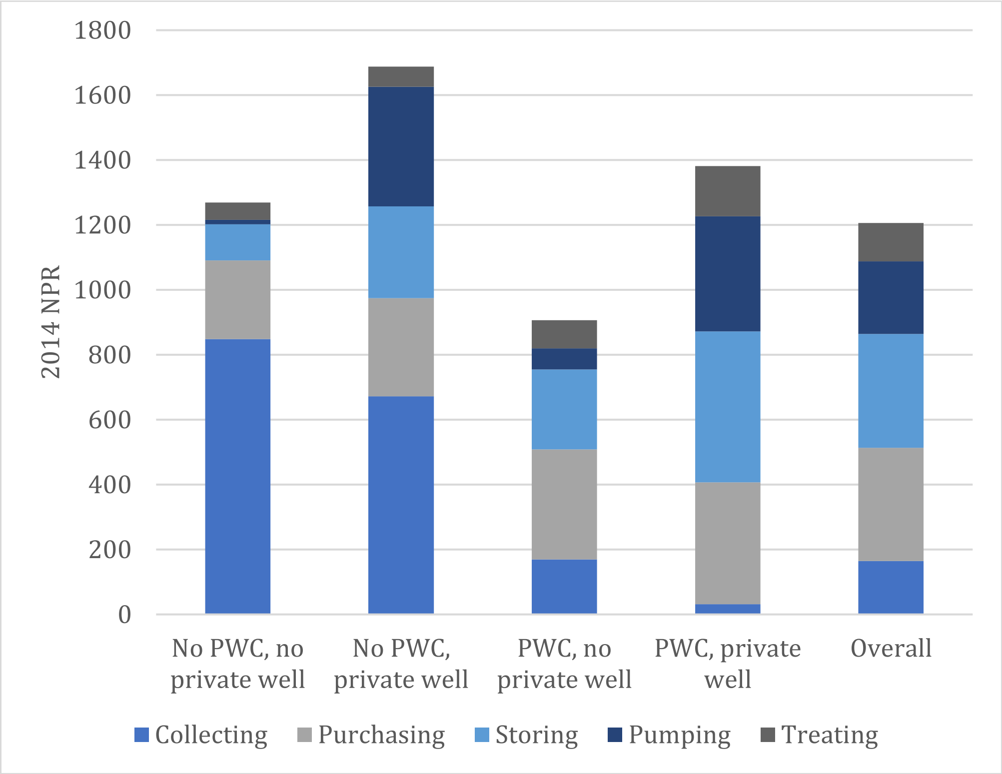


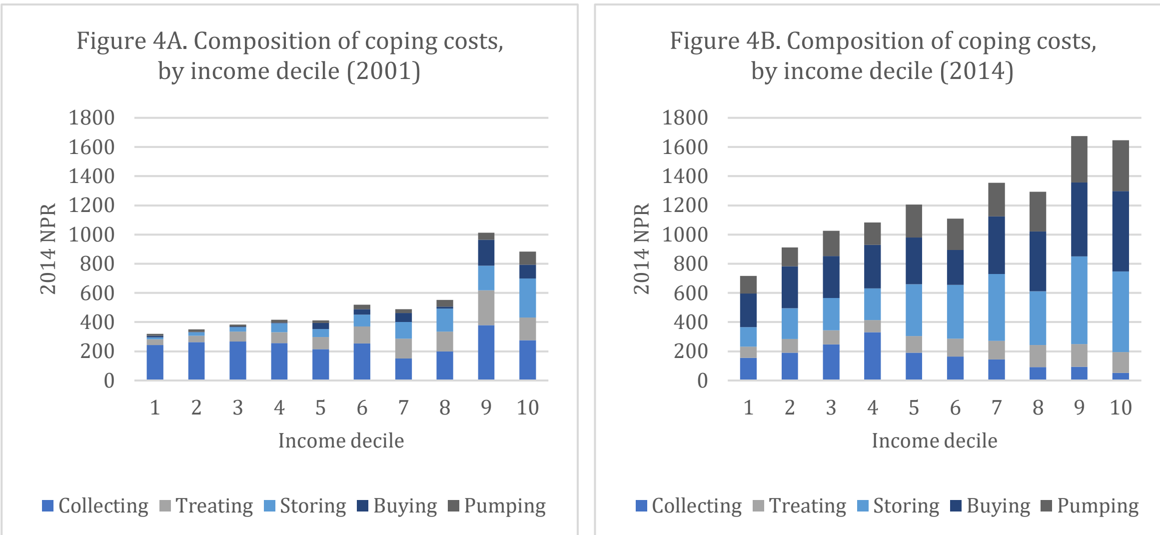
Table 4 also presents a comparison of the estimates of total household coping costs in 2001 and 2014. Average household coping costs have more than doubled in real terms over the period from 2001 to 2014, from 524 NPR to 1206 NPR (both in 2014 NPR). Because real household incomes have increased about 36%, coping costs for the average household have increased as a proportion of total income (from about 2% to 3%).

Table 4 also presents a summary of household-level changes in real coping costs by coping cost component and household type. Households have on average increased their coping costs by 682 NPR per month. The only component of coping costs that decreased from 2001 to 2014 was the time spent collecting water (by an average of 121 NPR per month). Pumping costs increased by 233 NPR; storage costs increased by 272 NPR; and expenditures on water vendors increased by 472 NPR. Treatment costs stayed essentially the same in real terms, increasing by only 13 NPR.

Households without PWCs in 2014 that chose to collect water in either 2001 or 2014 experienced large increases in collection costs, while connected households experienced decreases in collection costs. Households with private wells had large increases in pumping costs. Some households without private wells in 2014 still incurred costs for pumping water from private connections to both overhead and in- ground storage tanks, but the increases in pumping costs were smaller than those for households with private wells. Households without either a PWC or a private well also experienced changes in coping costs similar to households in the other three groups—large increases in purchase costs and smaller increases in storing and treating. Households without a private water connection but with a private well experienced the largest increase in coping costs—1108 NPR per month. This was due to increases in collection costs (465 NPR per month), pumping costs (348 NPR per month), and purchases from vendors (416 NPR per month). There was, however, a small decrease in treatment costs. Households with a private water connection and no private well experienced a smaller increase in coping costs of 488 NPR, due mostly to the large increase in purchases from vendors, offset by a decrease in collecting costs. Households with both a PWC and a private well also experienced an increase in coping costs of 762 NPR per month. Despite a large decrease in collection costs for over half of these households, there were large increases in pumping and storing costs for nearly the entire subsample. There was also an increase in purchasing costs for over half of the households with both a PWC and a private well.

Figure 4 shows the composition of coping costs by income decile for 2001 and 2014, respectively. Two major shifts occurred over the period. First, the costs of time spent collecting water declined across most income deciles (all except the third and fourth deciles) because fewer households were collecting water from sources outside their homes, particularly in the higher income deciles. The reduction in the coping costs associated with time spent collecting water is most dramatic for low- income households. In 2001, over 75% of the total coping costs of households in the poorest decile was the value of time spent collecting water; in 2014, this percentage was only 20%. By 2014 households in the richest three income deciles effectively stopped spending time collecting water from outside the home.

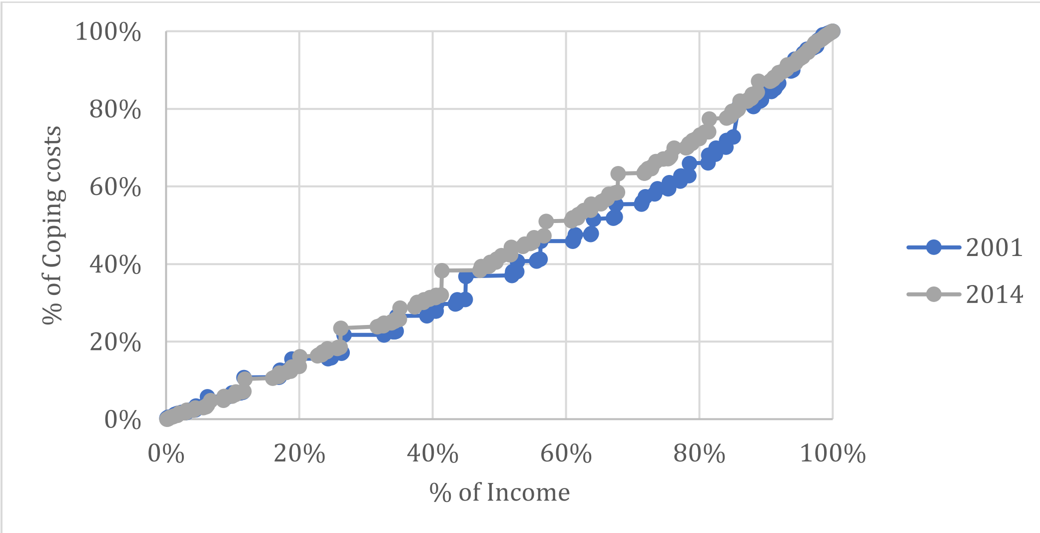
Figure 2.4. Composition of coping costs, by income decile (in 2001, 41 of 48 households who purchased from vendors bought from tankers, and expenditures were not recorded).



Second, monetary payments to water vendors rose dramatically. These monetary expenditures were for water purchases from both tanker trucks and bottled water vendors. In 2014 both poor and rich households were spending much more on vended water than in 2001.

To better understand the distribution of coping costs across income, Figure 5 presents the percentage of total coping costs on the vertical axis versus the percentage of households ranked from lowest to highest income on the horizontal axis in both 2001 and 2014. Figure 5 shows that the distribution of coping costs by household income has not changed much between 2001 and 2014. Households' coping costs were widely distributed throughout all income groups in the population in both 2001 and 2014. The coping costs per cubic meter average 198 NPR (US$2) in 2014, and there is little difference in coping costs per cubic meter between the poor and wealthy income groups.

Figure 2.5. Distribution of household coping costs by income, 2001 and 2014.



In 2001, average water bills for households with private connections were 152 NPR (in 2001 NPR) (387 NPR in 2014 NPR). By 2014, these had increased to only 218 NPR, a 44% decrease in real terms. In 2001, households with private connections paid about 133% more in monthly coping costs than their water bill. By 2014, monthly coping costs were approximately four times greater than their water bill.

Figure 6 illustrates the total monthly water supply costs for each of the four types of households in our typology. Figure 6 displays the total monthly costs as the sum of three cost categories: (1) the costs of publicly supplied (KUKL) water that are not paid by households with private connections (effectively the subsidies provided by government and donors); (2) the portion of the costs of the public supply paid by households through their water bill; and (3) the private coping costs households pay in addition to the costs of the water supplied by the public system. The total cost of water provided by KUKL (capital plus operation and maintenance) is assumed to be 95 NPR (US$1) per cubic meter. Figure 6 shows that private household coping costs make up the largest overall portion of the total costs of supplying water to households. The total costs to households with both PWCs and private wells, including the subsidies these households receive from taxpayers and donors, is the highest of the four groups.

Figure 2.6. Composition of total costs of water supply services, by household type (2014).

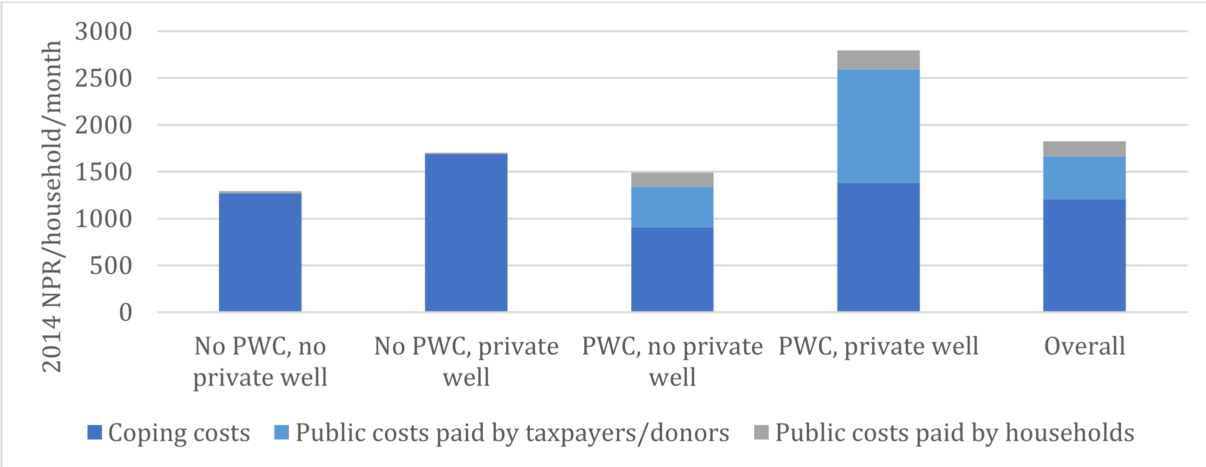


Table 2.5. Descriptive statistics

Variable name	Description	2001 Mean	2001 10p	2001 Median	2001 90p	2001 N	2014 Mean	2014 10p	2014 Median	2014 90p	2014 N	Difference Mean	Difference 10p	Difference Median	Difference 90p	Difference N
Coping	Total coping costs, 2014 NPR	476	48	321	978	927	1,198	201	895	2,515	927	722	-238	491	2,077	927
Respondent_edu	Respondent education, in years	8	0	10	13	927	8	0	9	16	927	0	-10	0	7	927
Respondent_hhhead	Respondent is household head (1=yes, 0=no)	0.4	0	0	1	927	--	--	--	--	--					
Respondent_male	Respondent is male (1=yes, 0=no)	0.6	0	1	1	927	0.6	0	1	1	927	0.4	0.0	0.0	1.0	927
Household_size	Household size	8.2	5	8	12	927	5.1	3	5	8	927	-3.1	-7.0	-3.0	0.0	927
Income	Income, 2014 NPR/month	38,027	11,482	25,515	67,616	927	57,452	18,000	43,000	100,000	927	19,425	-23,376	14,485	64,639	927
Uses_PWC	Uses a private water connection	1	0	1	1	927	0.7	0	1	1	927	--	--	--	--	--
Diff_PWC	Change in connection status (1=change, 0=no change)	--	--	--	--	--	--	--	--	--	--	0.2	0.0	0.0	1.0	927
Diff_PWCXGain_PWC	Interaction between change in connection status and gaining a PWC	--	--	--	--	--	--	--	--	--	--	0.1	0.0	0.0	1.0	927
Uses_privatewell	Uses a private well	0.3	0	0	1	927	0.4	0	0	1	927	--	--	--	--	--
Diff_well	Change in private well usage (1=change, 0=no change)	--	--	--	--	--	--	--	--	--	--	0.2	0.0	0.0	1.0	927
Diff_wellXGain_well	Interaction between change in private well usage and gaining a private well	--	--	--	--	--	--	--	--	--	--	0.2	0.0	0.0	1.0	927
N_sources	Number of sources used	2.1	1	2	3	927	2.6	1	2	4	927	0.5	-1.0	0.0	2.0	927
Service_hrs	Hours of service from PWC	1.1	0	0.6	2.5	927	1.4	0.5	1.0	2.7	927	0.3	-1.5	0.7	1.8	927
Taste_wet	Perception about taste of piped water in the wet season, 1=excellent to 4=poor	3.5	3	4	4	927	2.9	2	3	4	927	-0.6	-2.0	-1.0	1.0	927
Taste_dry	Perception about taste of piped water in the dry season, 1=excellent to 4=poor	2.8	2	3	3	927	2.8	2	3	4	927	0.0	-1.0	0.0	1.0	927
Color_wet	Perception about color of piped water in the wet season, 1=very clean to 4=very dirty	2.9	2	3	4	927	2.4	2	2	3	927	-0.6	-1.0	-1.0	0.0	927
Color_dry	Perception about color of piped water in the dry season, 1=very clean to 4=very dirty	2.2	2	2	3	927	2.2	2	2	3	927	0.0	-1.0	0.0	1.0	927
Health_wet	Perception about health risks of piped water in the wet season, 1=no risk to 4=serious risk	2.0	1	2	3	927	2.2	1	2	4	927	0.2	-1.0	0.0	2.0	927
Health_dry	Perception about health risks of piped water in the dry season, 1=no risk to 4=serious risk	2.4	2	2	3	927	2.3	1	2	4	927	-0.1	-1.0	0.0	1.0	927
Reliab_wet	Perception about reliability of piped water in the wet season, 1=very regular to 4=unreliable	2.7	2	3	3	927	2.3	2	2	3	927	-0.4	-1.0	0.0	1.0	927
Reliab_dry	Perception about reliability of piped water in the dry season, 1=very regular to 4=unreliable	3.1	2	3	4	927	2.9	2	3	4	927	-0.2	-1.0	0.0	1.0	927
Concern_water	Belief that water issues are the most important environmental problem	0.8	0	1	1	927	0.8	0	1	1	927	--	--	--	--	--
Diff_water	Change in beliefs about importance of water issues	--	--	--	--	--	--	--	--	--	--	0.3	0.0	0.0	1.0	927
Diff_waterXBecome_water	Interaction between change in beliefs and changing beliefs about water issues from not the most important to the most important environmental problem.	--	--	--	--	--	--	--	--	--	--	0.2	0.0	0.0	1.0	927

2.7. Explaining Differences in Total Household Coping Costs (2001 Versus 2014)

Table 5 presents the summary statistics for the variables used in the regression analysis. Table 6 presents the results for three different specifications of the model described in section 4, estimated using only the matched households. For each of the three specifications, we first run the regression with only the arguably exogenous variables (household characteristics) and then with the entire set of independent variables of interest. Models 1 and 2 use differences between 2001 and 2014 for all variables and are our preferred specifications because they control for time invariant factors. We run the same model using only the 2001 data (Models 3 and 4) and then with the 2014 data (Models 5 and 6). We discuss the results from Models 1 and 2 here (results of Models 3–6 are discussed in the Appendix).

Additionally, the Breusch-Pagan test for heteroskedasticity is conducted for all the models. The null hypothesis of homoskedasticity is rejected for all models; therefore, White's [1980] heteroskedastic-consistent covariance matrix estimator is used to correct the estimated standard errors for an unknown form of heteroskedasticity.

Model 1 focuses on the effects of four arguably exogenous household characteristics—respondent education, gender, household size, and income. Respondent education and gender are not significant. However, the coefficients on household size and income are positive and statistically significant, indicating that households with higher incomes and more members have higher coping costs.

In Model 2, income and household size effects are robust to the addition of variables in the full model. The coefficient on gaining a private water connection is negative and significant at the 1% level, indicating that obtaining a private water connection is associated with decreases in coping costs. The coefficient on having a private well is not statistically significant, nor is the coefficient on having both a private well and private water connection. The number of sources used has a positive and statistically significant association with household coping costs.

The magnitude of the effect of gaining a private water connection is the sum of the coefficients on *Diff_PWC* and *Diff_PWCXGain_PWC*, which is 287. To illustrate this effect, we can forecast the decrease in coping costs that households without either a private water connection or a private well would experience if they were to obtain a private connection. The predicted change in coping costs for a household that does not have a PWC in 2001 and is still unconnected in 2014 is estimated to be 732 NPR. The predicted change in coping costs for households that gain a private water connection is 445 NPR. This difference of 287 NPR is the decrease in coping costs attributable to obtaining a private water connection.

Almost all perceptions about the quality of piped water (in terms of taste, color, health risks, and reliability) do not have robust, statistically significant associations with coping costs. Only poor reliability in the dry season is significantly associated with higher coping costs. This is surprising, given findings from other studies in the literature, which highlight the importance of perceptions about the desirable qualities of water supply [*Um et al.*, 2002; *Abrahams et al.*, 2000; *Katuwal and Bohara*, 2011]. We would expect, given our larger sample size, to have enough power to detect an effect if one existed.

Based on the results of Model 2, we conclude that household income, having a private connection, household size, number of sources used, and perceived (un)reliability of piped water in the dry season have the strongest associations with coping costs. The positive association of household income and coping costs suggests that improved water service is a normal good, and demand increases with income. The negative association of having a private water connection and coping costs suggests that having a heavily subsidized water supply from the piped network is valuable to a household, even if the service is unreliable and the quality of the water provided is poor. Additionally, having a larger household, using more sources, and a PWC that is perceived to be unreliable are associated with higher coping costs.

Table 2.6. Regression results

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	diff_coping	diff_coping	coping2001	coping2001	coping_2014	coping_2014
Respondent_edu	8.890	7.325	7.061	10.33	27.79***	27.92***
	(6.249)	(6.110)	(6.307)	(6.308)	(7.460)	(6.877)
Respondent_male	-104.5	-130.0*	-20.28	-38.14	-38.77	35.11
	(80.11)	(78.50)	(50.00)	(49.79)	(68.11)	(64.58)
Household_size	36.70***	23.14**	-3.019	-5.296	52.68***	32.76**
	(11.23)	(10.72)	(7.293)	(7.084)	(16.94)	(16.43)
Income	0.902*	1.213**	1.465**	1.729***	0.833	1.141*
	(0.508)	(0.487)	(0.596)	(0.636)	(0.587)	(0.622)
Uses_PWC				-252.1***		-110.3
				(92.19)		(93.38)
Diff_PWC		296.7**				
		(122.4)				
Diff_PWCXGain_PWC		-583.7***				
		(181.1)				
Uses_privatewell				-93.05		205.3
				(107.3)		(149.5)
Diff_well		20.48				
		(159.0)				
Diff_wellXGain_well		-106.1				
		(166.4)				
Uses_PWCX Uses_privatewell				-66.34		-25.32
				(111.7)		(157.9)

Gain_both	906.4		
	(585.7)		
N_sources	288.9***	-59.62	287.6***
	(30.26)	(43.31)	(34.97)
Service_hrs	7.315	19.91	58.82**
	(13.41)	(43.49)	(26.13)
Taste_wet	-33.01	-104.5*	46.24
	(54.06)	(56.95)	(85.56)
Taste_dry	69.37	-63.43	-58.40
	(58.76)	(55.04)	(90.15)
Color_wet	17.74	-33.51	66.63
	(67.48)	(51.33)	(79.17)
Color_dry	-24.53	-10.07	90.68
	(76.11)	(47.76)	(85.91)
Health_wet	52.02	17.56	-23.97
	(61.35)	(53.28)	(90.38)
Health_dry	14.76	75.97*	172.2*
	(57.34)	(42.30)	(87.99)
Reliab_wet	-69.24	-74.13	-75.95
	(49.58)	(47.24)	(57.96)
Reliab_dry	106.2**	77.33*	108.8**
	(50.18)	(42.44)	(52.20)
Concern_water		-72.27	-44.96
		(47.95)	(74.27)
Diff_water	83.94		
	(109.9)		
Diff_waterXBecome_water	-266.9*		

		(138.3)				
Constant	1,008***	712.8***	446.1***	513.7*	865.3***	-837.0***
	(103.7)	(125.0)	(103.2)	(289.5)	(134.6)	(321.4)
Observations	927	927	927	927	927	927
R-squared	0.068	0.202	0.042	0.204	0.119	0.246

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

2.8 Discussion

Our resurvey of 1500 households first interviewed in 2001 has enabled us to better understand how households in Kathmandu have managed to cope with an increasing water shortage and lack of investment in public water supply infrastructure. After 2001, private water vendors have stepped into the water economy of Kathmandu and have provided a significant portion of the increased investment and water supplies that the public desperately needed. In 2001, only 71 out of 1500 households in our sample purchased water from tanker truck vendors or from bottled water vendors. In 2014, every single household in our sample (except one) reported that they purchased water from vendors (either tanker truck or bottled water) at some time during the year. Additionally, households have made private investments in water storage and private wells. Only households with both a private connection and a private well (49% of sample households) managed to obtain an arguably sufficient quantity of water (94 lpcd). Households without either a private connection or a private well used only 35 lpcd.

Real coping costs have more than doubled between 2001 and 2014, to an average of US$12 per household per month. The burden of coping costs falls evenly throughout the income distribution. The coping costs per cubic meter are also not significantly different across income groups. Rising household incomes over the period from 2001 to 2014 allowed households to install more storage tanks, drill more private wells, and pay tanker truck and bottled vendors for water, resulting in increased coping costs for dealing with the poor quality, unreliable supplies from the public system. These private investments have resulted in a decline in the time households spend collecting water from outside the home. Despite the increase in household incomes, households still experienced an increase in the percentage of their income spent coping with poor quality, unreliable public water supplies (from 2% to 3%).

Households with private connections incurred coping costs of US$12.49 per month (1,187 NPR), four times higher than their water bills (US$3.03 or 288 NPR per month). Even the poor quality services of the existing PWCs are more valuable to households than the water bills that they pay. Our regression analysis shows that gaining a PWC is associated with a decrease in coping costs. Currently, household perceptions about the taste, color, and health risks of the water from piped connections do not have significant relationships with coping costs. Only poor reliability has a significant association with higher coping costs, suggesting that this is the service attribute of piped water services that households care most about.

As shown in the theoretical framework, our coping cost estimates are simply one component of a household's willingness to pay for improved water quality and are only suggestive of the long-run demand for improved public water supplies. For example, our coping cost estimates will not capture the anxiety and stress households experience as they struggle with the uncertainty associated with accessing water from multiple sources, especially during the dry season. However, because coping costs are a significant portion of household expenditures, there is potential for large water supply improvement projects, such as the MWSP, to increase household welfare. The decreases in coping costs that would result from increased investments in public water infrastructure would be largest for households that obtain a new PWC, have less reliable PWCs now, and are able to decrease the number of sources used. These households are thus the most likely to experience increases in household welfare when the public water supply system in Kathmandu is improved. However, because our coping cost estimates cannot be interpreted as lower bound estimates of household willingness to pay for improved piped services in the short run, we are unable to predict the magnitude of the welfare improvements that will accrue to households that have made substantial capital investments in private wells and pumps, storage tanks, and in-house water treatment systems.

Our results have implications for the reform of water tariffs in Kathmandu. The completion of a large water supply improvement project, the MWSP, represents a unique opportunity to reform municipal water tariffs and put KUKL on a sounder financial footing. An increase in municipal water tariffs for households that experience an improvement in the quality and reliability of piped water services will allow the water utility to share the economic and financial benefits that will accrue to households. If there is not a substantial tariff increase when the MWSP is completed and municipal water services improve, households will grow accustomed to high quality services at very low prices, and it may be even harder to reset tariffs in the future.

The redesign of water tariffs will remain challenging. On one hand, the significant increase in water supply after the completion of MWSP should allow the water utility to capture some of the savings in coping costs that some households will experience, especially potential cost savings resulting from reduced purchases of vended water. On the other hand, we emphasize that the design of the new tariffs will need to consider the competition from the private vending sector and from the fact that many households have already incurred the costs of installing private wells.

Both vendors and private wells are alternative water sources for households and represent competition for the water supplied by public water utility from public taps and private connections. However, from the households' perspective, the cost and quality attributes of water supplied by vendors and private wells are quite different. Water from tankers and "jar" vendors is of relatively high quality. Marginal costs are high, but investment costs are minimal. Households can easily stop purchases of water from vendors.

However, the use of water from a private well requires substantial upfront investment costs and marginal costs, once the well and pump are installed, are low (mainly electricity costs for running the pump and minor repairs). However, there is an additional dimension to the economics of private wells. As more and more households have drilled wells, the groundwater table in Kathmandu has been falling. This means that households with private wells may find that they can no longer easily reach the groundwater, i.e., their well needs to be deepened to reach the falling groundwater table, incurring additional capital costs.

Finally, it is important to emphasize that although coping costs are related to the benefits of the MWSP, the objective of this paper has not been to reanalyze the costs and benefits of the MWSP, or to consider possible solutions to water scarcity in the Kathmandu Valley in addition to interbasin transfer. For example, conceptually the recycling of wastewater is an alternative water "tap" that could be used instead of an interbasin transfer. Singapore provides a good example of how this can be done. However, the capital costs and technical capacity required to actually implement this solution are out of reach in Kathmandu. Indeed, to the best of our knowledge, recycling wastewater for potable use has not been accomplished in any low-income country, certainly not any country with GDP per capita as low as Nepal.

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CHAPTER 3: WATER AND TIME USE: EVIDENCE FROM KATHMANDU, NEPAL[2]

3.1 Introduction

Access to water is costly in many developing countries. Households in these countries spend time and effort on collecting water, often on a daily basis, resulting in productivity and welfare losses. On average, the persons responsible for water collection (usually women and girls) spend 36 min per trip for water collection activities in rural Sub-Saharan Africa and approximately 23 min per trip in rural Asia (Cheung, 2010). In water-scarce regions in India, a woman could spend up to 3 out of her 15 productive hours per day collecting water (Sijbesma et al., 2009).

As a result, many developing countries have implemented large-scale programmes to provide tap water connections to households. The motivations underlying these programmes include the provision of safe and convenient water supply and consequently improve household welfare. However, rapid expansion of tap water connections can lead to inadequate supply if it is not accompanied by improvements to the supporting water infrastructure, thus undermining the effectiveness of providing tap water connections.

In this paper, we study the effect of reliability of private tap water connections (PWCs) on household time allocation and household welfare measured as volume of water consumed in Kathmandu, Nepal.[3] The importance of infrastructure on development and growth has been demonstrated in the existing literature. However, the importance of infrastructure quality has not

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[3] For simplicity, private tap water connections are referred to as 'tap water' hereafter.

received adequate attention, due to the thinking that quality will eventually catch up. In reality, in many countries, it takes decades, if not longer, for the infrastructure to operate at optimal capacity. During this lengthy period of catching up, households usually rely on existing sources of water supply, such as public taps or wells and private water markets to manage their household water supply. An interesting question that arises is whether access to tap water, even though unreliable, is better than nothing?

Tap water systems provide treated water from public sources to end users. The provision of tap water requires supporting infrastructure, such as water pipelines that link end users directly to the water source. However, as in many developing countries, the tap water system in Kathmandu suffers from intermittent service and poor reliability. Although over 70% of households had access to tap water in 2001, water pressure and running time varied significantly, owing mainly to weak supporting water infrastructure, such as aging and broken pipes, and depleting water sources (Whittington et al., 2002; Pattanayak et al., 2005). A majority of households get tap water only for a few hours every day. Under these conditions, it is unclear what effect improved reliability would have on water collection times. At the time of the writing of this article, we were unaware of any other study examining time use patterns under conditions of unreliable water supply.

We use unique household data collected in the Kathmandu Valley for our analyses. Kathmandu Valley is the economic and political centre of Nepal. With its rapid urbanisation and growing population, Kathmandu Valley has experienced significant water shortages. Although in our sample, 87% of households had access to tap water, the connections can be highly unreliable. Data on household water usage collected by the authors from 2014 to 2015 indicate that, on average, households with tap water connectivity received water from their tap for only 9 days out of a month, and for the days when water was available, it only runs for less than 100 min. Tap water reliability contributes significantly to household time allocation decisions. During our survey, many respondents suggested that they often needed to leave work early in order to turn on the tap when the water became available.

We provide a simple theoretical model that illustrates the effect of increased productivity of household water production (that is, when tap water is more reliable) on households' time use and water consumption. Our model shows that without imposing specific functional forms on households' water production, the effects remain ambiguous. If a linear production function is imposed, households would be expected to consume more water but the amount of time they spend on collecting water still remains ambiguous.

We use a subsample of 819 households connected to tap water for our empirical analyses. Using the detailed household survey and time diary, we first demonstrate that the time spent on water collection activities is negatively correlated with productive activities. For every one minute increase in time spent on water collection, there is about half a minute reduction in time spent on work. However, we find no evidence that time spent on water collection affects the probability of employment. We also demonstrate that the reliability of tap water was positively correlated with time spent on water collection. In particular, if a household had regular tap water, water collectors spend 17–23 min more on water collection per day (compared to a household with less regular tap water). Further analysis suggested that this increase was largely driven by the increase in time spent on collecting water from the private tap. In estimating the relationship between tap water reliability and water consumption, we find the reliability measure to be positively correlated with total water consumption and water consumed from the tap. In the meantime, households with reliable tap water consume less water from public sources (such as public wells and public taps) and water vendors. Note that the empirical findings we present in this paper can only be interpreted as correlations and not causal relationships owing to potential endogeneity in access to tap water as well as its reliability. We perform additional robustness checks to confirm if our estimates were sensitive to the choice of control variables or different fixed effects.

Our study adds to the current literature on reliable access to water and time use in a number of ways. First, this study contributes to the understanding of tap water reliability and time use in urban areas of a less developed country. As women are usually responsible for water collection in developing countries, most of the existing literature has tended to focus on the effects of improved access to water on female labour markets and domestic labour supply outcomes (Ilahi & Grimard, 2000; Koolwal & van de Walle, 2013). Little is known, empirically, about how access to tap water affects time spent on water collection and other daily activities.[4] Second, we provide new evidence that can be added to the existing literature on infrastructure reliability and intermittent water supply. Past literature that evaluated the effect of infrastructure tended to focus on a categorical change, and less attention has been paid to its quality and reliability (Chen et al., 2019). Our results indicate that intermittent water supply could hurt labour productivity if water becomes available during working hours. It also suggests that there might be a welfare effect of improved reliability of tap water. Households with more reliable tap water spend less time outside the house collecting water and consume more from the tap. Therefore, although the total amount of time they spend on collecting water is more, they can probably accomplish other things alongside water collection at home, leading to a potential welfare gain. This study is also the first to use a detailed time diary to estimate the effect of reliable tap water on time use. It allows us to disaggregate time allocation across broad activity categories.

3.2 Conceptual Framework

In this section, we present a simple theoretical model that links the productivity of household water production with time use and water consumption. Suppose a household is set out to maximise $U(c_1; c_2; l)$, where c_1 is the consumption of water, c_2 is the consumption of other

[4] Studies on this topic in the existing literature have usually focused on rural households. For example, Gross et al. (2018) demonstrated that the installation of public water access points significantly reduced time spent on water collection in rural Benin. Meeks (2017) discovered that improved water access in rural Kyrgyzstan increased the time spent on market activities and leisure.

market goods and l is leisure. Suppose water can be collected from a private tap or other sources (such as a private well or a public tap). The household's problem can be written as follows:

$$Max_{t_1,t_2,t_w} U(c_1, c_2, l)$$

$$\text{s.t.: } c_1 = g(t_1;\theta_1) + v(t_2;\theta_2)$$

$$pc_2 = wt_w \tag{1}$$

$$t_1 + t_2 + t_w + l = T$$

where $g(t_1;\theta_1)$is the production function of water from a private tap and $v(t_2;\theta_2)$ is the production function of water from other sources. θ_1 and θ_2 are parameters in the production functions, which indicate the productivity of water production from various sources. p is the price for market goods. Household is endowed with time T, which can be allocated to the production of water from the private tap (t_1) or other sources (t_2) to the labour market at wage rate w (t_w) and leisure (l).

Note that Equation (1) is equivalent to maximising $U(g(t_1) + \ v(t_2), wt_w/p \,, T - t_1 - t_2)$. The research question of interest is as follows: What is the effect of θ_1 on time allocation and water consumption? We can show that these effects are ambiguous, that is, the signs of the partial derivatives $\partial t_1/\ \partial\theta_1,\ \partial t_w/\ \partial\theta_1,\ \partial c_1/\ \partial\theta_1$ cannot be determined.[5] Intuitively, this is because as the productivity of tap water production increases, there are two forces driving time t_1 allocated to this activity. On the one hand, the substitution effect will lead to an increase in t_1 compared to other activities, as the production of tap water becomes more efficient in terms of labour (hence per unit price becomes cheaper). However, this substitution effect can be bounded above as the quantity of water consumed in a household cannot increase infinitely. On the other hand, an increase in tap water productivity will have an income effect. This income effect will push demand for all consumption upwards, including demand for market goods and leisure. This income effect will

[5] The proofs are omitted here.

induce households to supply more labour to the labour market in exchange for market goods. In equilibrium which effect dominates is ambiguous.

Koolwal & van de Walle (2013) discussed a special case of the model presented in Equation (1), where the tap water production function is assumed to be linear, that is, $g(t_1) = \rho t_1$. Under this assumption, if a household reallocates time spent on producing water from a private tap, t_1, to the labour market, it can earn a wage income of wt_1. If the price of a market good is assumed to be numeraire, the reallocation of time results in wt_1 units of additional consumption of the market good, but now the household produces t_1 units of water from its private tap. Therefore, the relative price of water produced from the private tap to market good is w/ρ. Applying the Slutsky equation, it can be shown that $\partial c_1/\partial\rho$ is always negative. Therefore, the authors conclude that under the assumption of a linear production function, as ρ increases, the consumption of home-produced water will always increase. Nonetheless, even under this restrictive assumption, the sign of $\partial t_1/\partial\rho$ remains ambiguous.

To summarise, when tap water becomes more reliable, it is unclear from the model whether time spent on water collection will increase or decrease. This lack of clarity is due to the fact that the substitution effect and income effect from such a change work in opposite directions. However, if stricter assumptions on the water production function are imposed, an increase in total water consumption should be expected while the effect on time allocation remains ambiguous.

3.3 Data and Outcome Variables

Data for the empirical analyses presented in this paper were drawn from a household survey of 1,500 households in five municipalities in the Kathmandu Valley in 2014 and 2015 (Kathmandu, Lalitpur, Bhaktapur, Kirtipur and Madhyapur). This was a follow-up survey of the 2001 wave in the same area. The two waves were merged to construct a panel. Details of the sampling strategy and data for the 2001 wave can be found in Whittington et al. (2002) and Pattanayak et al. (2005), and details of the 2014–2015 survey can be found in Yogendra et al.

(2017). In this paper, we only use data from the 2014–2015 wave. The survey was conducted using a multi-stage clustered sampling method, and the sample is representative of the population of Kathmandu in 2001 but not of the population in 2014–2015. The 2001 survey collected information on household characteristics and water usage as well as perceptions of tariffs and willingness-to-pay. In 2014–2015, an attempt was made to re-survey all the households in the 2001 sample to construct a panel. If a household could not be located in the 2014–2015 survey, the current resident or the immediate neighbour was interviewed. In total, 61.8% of households were successfully re-surveyed. We only use households that were surveyed in both rounds for our analyses.

The 2014–2015 survey included a time diary module. The time diary was distributed at the time of survey, and in it, household members were asked to reflect on the activities that they performed in a typical day over a 24-hour period, using 30 min as the smallest block (see Figure 1). Following the standards of the established literature, we provided 26 types of activities for respondents to choose from Devoto et al. (2012). The respondent of the main survey, spouse of the respondent, and the person most responsible for water collection (if different from respondent or spouse) filled out the time diary. We grouped the 26 activities into seven broad categories: work, leisure, household chores, social activities, rest, water collection and meal times.

Literature on survey methods and cognitive psychology has highlighted potential bias that might be introduced in time use data arising from recall and salience of activities (Menon, 1993; Beegle et al., 2012; Arthi et al., 2018). In particular, the concern is that respondents are likely to over(under)-report time spent on different activities depending on the recall period and whether the activities are salient and regular. For instance, if time spent on collecting water is less salient but regular, such as ‘every afternoon’, then respondents may not respond with precise recall-and-count strategy but instead just recall the periodicity (Menon, 1993).

We designed the time use module acknowledging these limitations. First, we did not impose a specific recall period; instead, we asked the respondents about a ‘typical day’. Second, we did not explicitly highlight certain activities, such as 'how much time do you spend on collecting water'. Instead, we let the respondents recall their daily activities chronologically over a 24-hour period, and then we post-coded those activities. It is possible that our survey data collection method may have introduced bias such as respondents sub-consciously reporting more time spent on collecting water since they were informed a priori that the survey was about water supply. However, taking into consideration the resource and time constraints of implementing the survey, this was the best way forward.

Figure 3.1. Time use survey (time diary) for the 2014–2015 survey

3. TIME-USE SCHEDULE (Imagine a normal 24-hour day)
Respondent: (1) Respondent from first part survey OR (2) his/her spouse
About Whom: (1) Respondent from first part of the survey (2) Spouse of the respondent (3) Person most responsible for collecting water for the household (if different from the respondent or spouse) and (4) children aged 7-15 years who mostly assists in collecting water for the household

301. Respondent's name: ______________________ .... ID (From HH Roster) ☐☐
302. Who are other responsible for collecting water in your household? (Check the boxes by √ that applies)
1. Respondent................ ☐ 2. Spouse of respondent ...... ☐ 3. Other family member (if different)..... ☐ 4. Children (7-15 yrs) .... ☐

303. Among them, who is the most responsible person for collecting water? **Name:** ______________________ ......ID (From HH Roster): ☐☐

304. TIME	305. CODE				304. TIME	305. CODE			
	Ask for the boxes in Q302 are checked					Ask for the boxes in Q302 are checked			
	Respondent	Spouse	Other	Children		Respondent	Spouse	Other	Children
ID					ID				
5:00 - 5:30					17:00 - 17:30				
5:30 - 6:00					17:30 - 18:00				
6:00 - 6:30					18:00 - 18:30				
6:30 - 7:00					18:30 - 19:00				
7:00 - 7:30					19:00 - 19:30				
7:30 - 8:00					19:30 - 20:00				
8:00 - 8:30					20:00 - 20:30				
8:30 - 9:00					20:30 - 21:00				
9:00 - 9:30					21:00 - 21:30				
9:30 - 10:00					21:30 - 22:00				
10:00 - 10:30					22:00 - 22:30				
10:30 - 11:00					22:30 - 23:00				
11:00 - 11:30					23:00 - 23:30				
11:30 - 12:00					23:30 - 24:00				
12:00 - 12:30					24:00 - 00:30				
12:30 - 13:00					0:30 - 1:00				
13:00 - 13:30					1:00 - 1:30				
13:30 - 14:00					1:30 - 2:00				
14:00 - 14:30					2:00 - 2:30				
14:30 - 15:00					2:30 - 3:00				
15:00 - 15:30					3:00 - 3:30				
15:30 - 16:00					3:30 - 4:00				
16:00 - 16:30					4:00 - 4:30				
16:30 - 17:00					4:30 - 5:00				

SCHEDULE CODES	
1	Sleep
2	Bathing and freshening
3	Tea time/breakfast
4	Read newspaper
5	Dressing, getting ready
6	Commuting to/from work/school/college
7	At work (include self-employment/own business)
8	Eat meals
9	Cooking
10	Washing and cleaning
11	Collecting water
12	Other domestic chores
13	Resting
14	Go to the market
15	Take care/help children and aged in the family
16	Spend time with persons in the household
17	Socialize with friends, neighbors, community
18	Professional training
19	Religious and spiritual activities
20	Entertainment – TV, DVDs, radio, internet, movies
21	Phone calls, letters, emails
22	Exercise – walking, jogging, gym, sports
23	At school/college, doing homework, studying
24	Playing (indoors or outdoors)
25	Pursue hobbies – reading, writing, drawing, music, dance
26	Other (Specify)

Similarly, the data we constructed for the quantity of water consumed from various sources are subject to measurement errors. Existing literature has usually relied on self-reported water usage or imputed data from recalled water expenditure to infer household water consumption volumes (Fuente et al., 2016; Apoorva et al., 2018). The difficulties in accurately estimating the quantity of water consumed are twofold. First, confidentiality concerns prevent disclosure of socioeconomic status in water bills. As a result, researchers are not able to link metered water usage to household characteristics in many countries. In addition, households in developing countries usually gather water from various sources, many of which are not metered. Water consumption from these sources can only be estimated based on recall data. In our survey, we also relied on the recall method to gather information on the amount of water consumed. We asked households about their water consumption from 11 sources. For consumption from sources other than private taps, we follow the standard practices of the existing literature and asked respondents to report the size of their containers and the number of containers they retrieved per trip (Apoorva et al., 2018).

The two sets of outcome variables of interest are time spent on collecting water and total water consumption from various sources. We discuss the main variables used in the empirical analyses in the following paragraphs.

3.3.1 Time Spent on Water Collection

We constructed two variables to measure time spent on water collection. The first variable is '*activity_water*'. This variable was constructed from the time diary module. Respondents only reported the amount of time they spent on collecting water (if at all) during the day and did not differentiate it by source. Therefore, we could not disaggregate time spent on collecting water from a private tap or from other sources. To supplement this, we constructed a second variable '*activity_water_outside*' using information from the household survey. This variable measures the time (minutes per day on average) spent on collecting water from a public tap, public well or a stone tap. Time spent on collecting water from outside the household was computed by adding up round trip time plus waiting time for collection from these sources. This number was reported by the main survey respondent, and he or she could be different from the person who was most responsible for water collection activities in the household. Our data indicated that out of the 1,500 respondents for the main household survey, 412 filled out the time diary module (out of a total of

819 time diaries). Hence, the variable *activity_water_outside* is subject to measurement errors, and the results need to be interpreted with caution.

3.3.2 Water Consumption from Various Sources

We collected data for water consumption from the following sources: a private tap, any public sources (including public tap, public well and stone tap), a private well, water vendors and total water consumption from all sources. These variables were constructed from the main household survey conducted in the 2014–2015 period. In particular, in the main household survey, each respondent (usually the head of the household who may not be the person most responsible for water collection) was questioned about the availability of various water sources. We constructed the water consumption variables by adding up consumption in the corresponding categories.

3.3.3 Measures of Productivity of Home Water Production

We constructed two measures of reliability for tap water connection. The first measure is a qualitative, ordinal measure of reliability. The respondent of the household survey was asked to judge the reliability of tap water on a scale of 1–4, with 1 being 'very regular' and 4 being 'unreliable', for both the dry and rainy seasons. We generated a dummy variable that is equal to 1 if the respondent reports that the tap water connection is 'very regular' or 'regular'. We used the responses for reliability of tap water in the dry season in our main results.

The second reliability measure uses Hashimoto et al. (1982)'s definition of a system in water resources planning: the frequency or probability that a system is in a satisfactory state. We calculated the probability of getting tap water in the next hour. Specifically, we computed the following measure:

$$reliable\_hrs = \frac{tap\_minutes/60}{24 \times (1 + tap\_gap)} \tag{2}$$

tap_minutes are the number of minutes of tap water a household expects to receive every time they receive water from the tap. *tap_gap* is the number of days between the time tap water is received.

Therefore, the measure *reliable_hrs* computes the probability that a household receives tap water in the next hour. For example, if a household receives uninterrupted tap water supply 24 hours a day, 7 days a week, the household's probability of getting tap water in the next hour would be ((24 * 60)/60)/(24 * (1 + 0)) = 100%.

Summary statistics for the sample used in the analysis are presented in Table 1. Since only the person most responsible for water collection answered the time diary, there were some missing observations if this person were absent or unavailable at the time of the survey. Out of the time diaries distributed to 1,500 households in the original sample, 819 of them were collected. We compared household income and household size of the 819 households against those that were missing from the original sample. Our t-test indicated that although the logarithm of household income was not statistically different between the two groups (P-value = 0.82 for two-sided test), households that answered the time diary survey had a slightly smaller household size (difference = 0.2, P-value = 0.037). We attempted to address the sample selection issue by including household controls and individual characteristics. We also performed additional robustness checks which are discussed in Section 5.

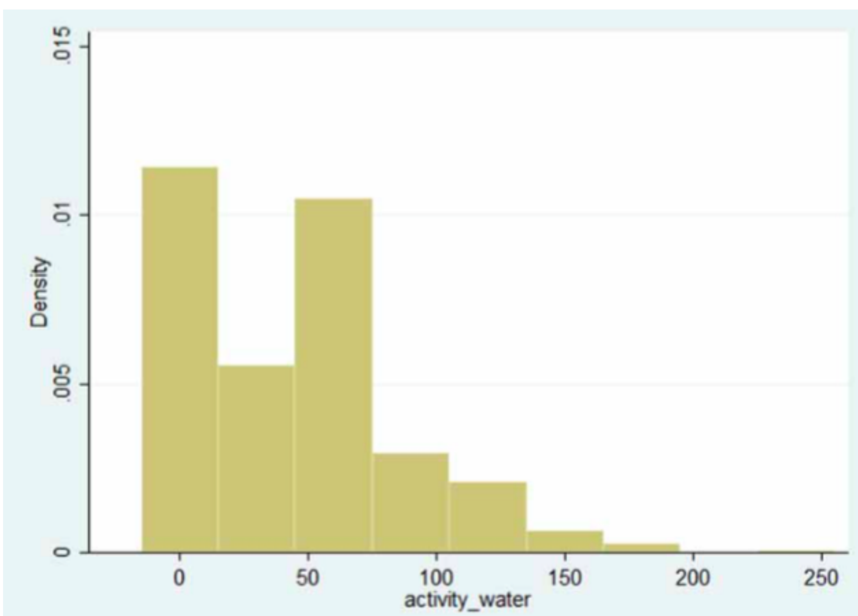
Table 3.1. Summary statistics

Variable	Description	Observed	Mean	SD	Min	Max
Key variables						
Time spent on water collection						
Activity water	Time spent on collecting water per day (minutes)	819	43.7	41.5	0	240
Activity water outside	Time spent on collecting water outside household per day (minutes)	819	8.7	34.1	0	540
Water consumption – dry season						
Water total dry	Total water consumption per day in the dry season (litre)	819	301	362	6.7	2775
Water pipe dry	Total water consumption per day from pipe in the dry season (litre)	819	78.6	136	0	2,000
Water public dry	Total water consumption per day from public well, tap or stone tap in the dry season (litre)	819	23.4	51.3	0	500
Water priwell dry	Total water consumption per day from private well (priwell) in the dry season (litre)	819	136	318	0	2,500

Water vendor dry	Total water consumption per day from vendors in the dry season (litre)	819	55	139	0	1,667
Water consumption - rainy season						
Water total rain	Total water consumption per day from pipe in the rainy season (litre)	819	361	413	5	2,917
Water pipe rain	Total water consumption per day from pipe in the rainy season (litre)	819	160	269	0	2,500
Water public rain	Total water consumption per day from public well, tap or stone tap in the rainy season (litre)	819	25.5	57.5	0	500
Water priwell rain	Total water consumption per day from private well (priwell) in the rainy season (litre)	819	133	308	0	2,000
Water vendor rain	Total water consumption per day from vendors in the rainy season (litre)	819	26.7	82.6	0	800
Reliability measures						
Reliable dry	Self-reported reliability of tap water connection in the dry season	819	0.24	0.43	0	1
Reliable rain	Self-reported reliability of tap water connection in the rainy season	819	0.75	0.44	0	1
Reliable hours	Probability of getting tap water in the next 24 h	575	1.56	1.89	0.06	20.8
Control variables						
hhsize	Household size	819	4.96	2.05	1	15
Age	Age of the respondent	819	46.3	14	13	90
Gender	Gender of the respondent	819	1.77	0.42	1	2
Education	Whether respondent has received middle school education	818	0.65	0.48	0	1
Inschool	Whether respondent is currently enrolled in school	819	1.97	0.18	1	2
Married	Whether the respondent is married	819	0.81	0.39	0	1
Lnincome	Logarithm of monthly household income (Rs)	795	10.4	1.28	6.21	16.1
Other time use variables (minutes per day)						
Work	Time spent at work	819	131	198	0	750
School/training	Time spent at school	819	7.22	50	0	570
Bathing/dressing	Time spent on taking a bath or dressing	819	36.7	19.3	0	150
Meals	Time spent on eating meals	819	136	44.8	0	270
Commute	Time spent on commuting	819	10.5	31.4	0	600
Sleep	Time spent on sleeping	819	441	50.4	270	630
Chores	Time spent on running household chores other than water-related activities	819	313	183	0	810
Leisure	Time spent on leisure activities	819	319	177	0	870

As shown in Table 1, although all households are connected to a private tap in our sample, on average, the probability for a household to receive tap water in the next hour is extremely low at only 2%. Households waited an average of 5 days for tap water to become available; these periods of availability on average lasted for approximately 100 min. A typical respondent still spent about 40 min on water collection activities every day. This included all water-related activities, including fetching water from the tap and from other resources within and outside the household. This number suggests that although households were 'connected' to a private tap, they still spent a great deal of time on collecting water. Figure 2 plots the histogram of time spent on water collection among the 819 households. The figure suggests that there was significant variation in time spent on collecting water among these households, and one possible explanation for this is the reliability of tap water connections across these households.

Figure 3.2. Distribution of time spent on water collection. Note: This figure shows the histogram of water collection activities (minutes/day) among the 819 respondents that completed the time diary in the 2014–2015 survey.



3.4 Descriptive Analyses of Tap Water Reliability, Time Use and Water Consumption

In this section, we present descriptive analyses of tap water reliability and time use. In particular, we examine the time use patterns across different household activities for households with good and poor connections.

3.4.1 Water Collectors

We paired the time diary records of the person most responsible for collecting water for the household with information in the household roster in the main household survey. Therefore, we had detailed data about who these water collectors were. Table 2 demonstrates that 43.8% of main water collectors were spouses and 28.9% were heads of households. It can be seen that 76.8% of water collectors were female. Daughters-in-law were also frequently tasked with collecting water. We also observed that sons, daughters, parents and other family members participated in collecting water. While the majority of water collectors were female, male water collectors made up 23% of the sample. Figure 3 shows the distribution of the age of water collectors. They had a mean (and median) age of 46. Only 11 households (out of 819) reported water collectors under the age of 18. We saw no significant participation of children in the collection of water. Our results, therefore, differed from much of the trend observed in the literature, as we have a significant portion of male collectors and few collectors who were children.

Figure 3.3. Age distribution of water collectors

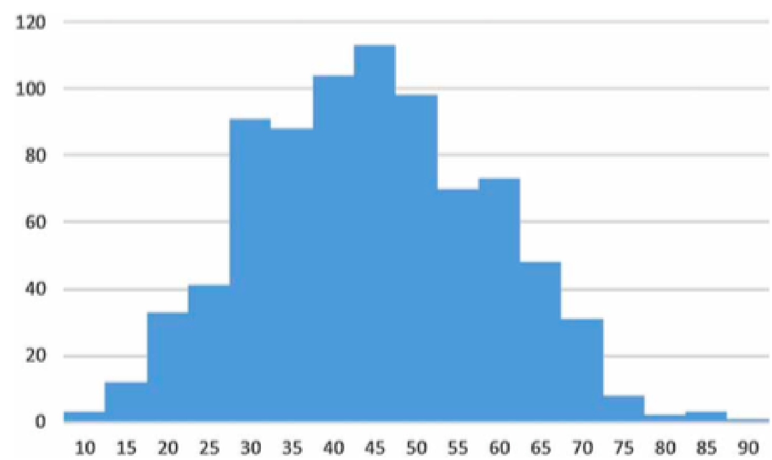


Table 3.2. Water collector's household role

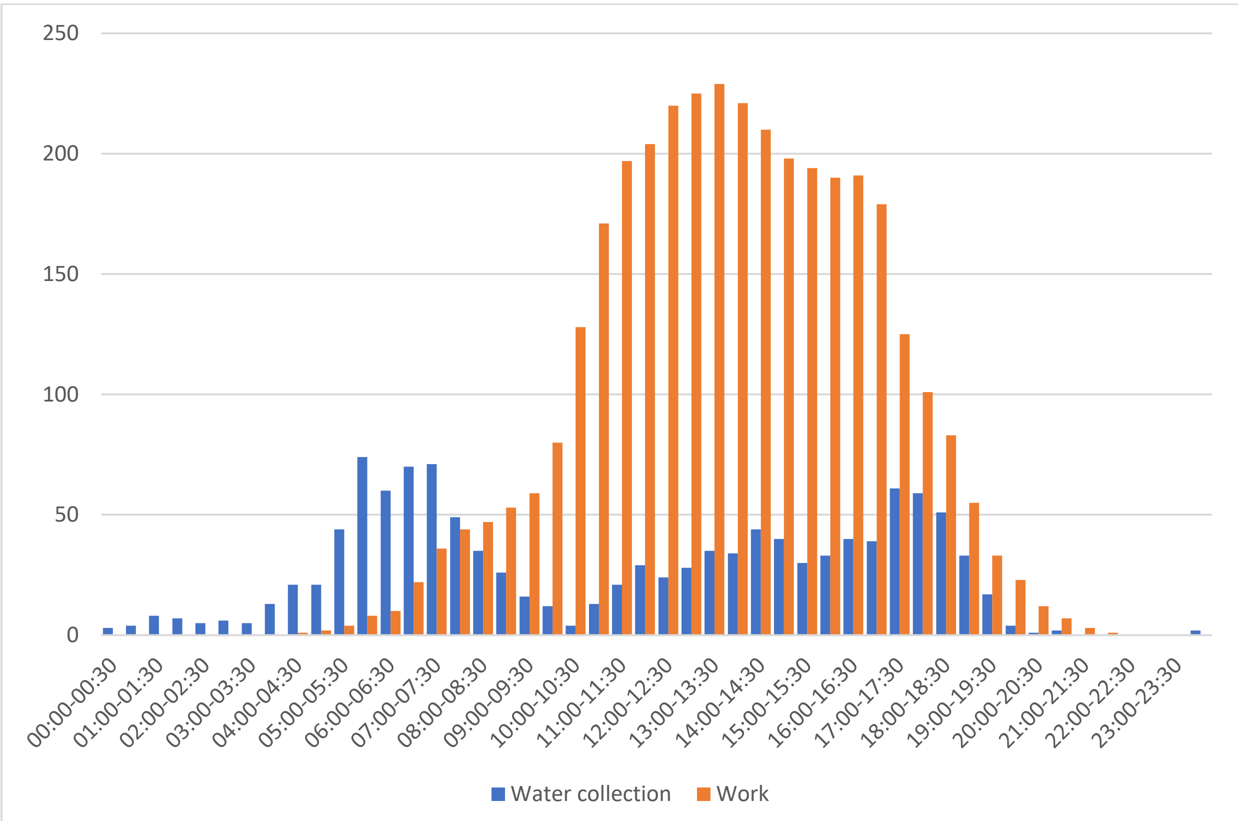
	Male	Female	Total
Spouse	1	358	359
Head	143	94	237
Son/daughter-in-law	1	121	122
Son/daughter	39	34	73
Father/mother	0	6	6
Other non-relative	2	4	6
Brother/sister-in-law	0	5	5
Grandchild	2	2	4
Brother/sister	0	3	3
Other relative	1	1	2
Nephew/niece	1	0	1
Father/mother-in-law	0	1	1
Total	190	629	819

Additionally, households often included more than one member responsible for collecting water. The results revealed that 82% of households had one main water collector, 18% had two collectors and 0.4% had three. Of the main collectors, one-third (33%, N = 276) reported working in a typical day.

3.4.2 Water Collection and Work

Next, we examined the water collection time patterns throughout the day. Figure 4 demonstrates the water collection patterns for the entire sample and contrasts it with working hours. Each bar represents the number of households reporting water collection during that half hour. It can be observed that a large portion of the water collection (in blue) occurs in the morning before 10:00 am. There is also a significant portion of water collection that occurs during work hours (illustrated using orange bars) and in the evening. Two smaller peaks can be observed at 2:00 pm and 5:00 pm.

Figure 3.4. Water collection time. Note: This figure displays frequencies of time intervals for water collection and work for all 819 respondents that completed the time diary in the 2014–2015 survey.



Because much of the literature has tended to focus on labour supply outcomes, we examined the relationship between water collection and work. First, we examined the observable socioeconomic differences between water collectors who work more and those who work less. We run regressions of the number of hours worked in a typical day on socioeconomic variables and on hours spent on collecting water and water reliability. In Table 3, it can be observed that in regressions (1) and (2), which controls only for socioeconomic characteristics, females, older people, individuals from bigger households and those currently enrolled in school work fewer hours. Marital status and education had no significant impact on hours worked. Fixed effects for municipality or ward or both were included in all models. Regressions (3)–(8) build upon models (1) and (2) by including variables related to tap water reliability and hours spent on collecting water. There was a significant negative coefficient on time spent on collecting water – more time spent on collecting water was associated with less time spent working. Reliability did not have a significant effect on hours worked. Table 4 presents the effect of time spent on water collection on the probability of employment. The coefficients on *activity_water* were significant when municipality fixed effects were controlled for but became insignificant when ward fixed effects were controlled for instead. This trend suggests that the observed correlation between water collection activities and the probability of employment might be driven by unobserved ward characteristics.

Table 3.3. Regression of time spent on water collection on hours worked

	Dependent variable = activity prod							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Activity water			−0.773***	−0.497***	−0.789***	−0.517***	−0.727***	−0.440**
			(0.156)	(0.172)	(0.160)	(0.173)	(0.189)	(0.204)
Reliable dry			2.371	−1.326				
			(15.698)	(17.651)				
Reliable rain					7.180	11.496		
					(15.814)	(16.268)		
Reliable hours							0.827	0.122
							(4.429)	(5.085)
Lnincome	12.053***	11.605***	12.413***	11.844***	12.334***	11.817***	13.788***	14.174***
	(2.553)	(2.580)	(2.492)	(2.533)	(2.499)	(2.535)	(3.262)	(3.390)
Household size	−13.909***	−14.050***	−13.553***	−13.461***	−13.456***	−13.387***	−13.888***	−15.060***
	(3.115)	(3.095)	(3.015)	(3.049)	(3.020)	(3.048)	(3.700)	(3.553)
Age	−3.014***	−3.051***	−3.164***	−3.112***	−3.149***	−3.103***	−3.425***	−3.338***
	(0.483)	(0.481)	(0.483)	(0.480)	(0.482)	(0.481)	(0.587)	(0.598)
Gender	−150.921***	−148.143***	−158.654***	−151.675***	−159.009***	−152.037***	−171.595***	−167.033***
	(18.790)	(18.318)	(18.445)	(18.191)	(18.425)	(18.168)	(22.020)	(21.981)
Education	−2.727	−0.658	3.797	2.764	4.367	3.734	5.376	0.712
	(14.146)	(14.266)	(14.000)	(14.259)	(14.126)	(14.378)	(16.726)	(16.913)
In school	130.100***	112.464***	132.422***	112.067***	133.105***	113.871***	151.471***	137.258**
	(42.344)	(42.440)	(42.779)	(42.808)	(42.953)	(43.108)	(51.691)	(54.015)
Married	−24.381	−18.112	−26.140	−19.753	−25.904	−19.947	−32.121	−25.213
	(18.467)	(18.563)	(18.320)	(18.555)	(18.260)	(18.530)	(22.241)	(22.319)
Observations	790	790	790	790	790	790	556	556
R^2	0.137	0.192	0.161	0.200	0.161	0.200	0.171	0.219
Municipal FE	Y	N	Y	N	Y	N	Y	N
Ward FE	N	Y	N	Y	N	Y	N	Y

Notes: ***, ** and * denote significance level at 1%, 5% and 10%, respectively. Robust standard errors are in parentheses. Activities are measured in minutes/day. See Section 3 for more details on variable definitions. Y, yes; N, no.

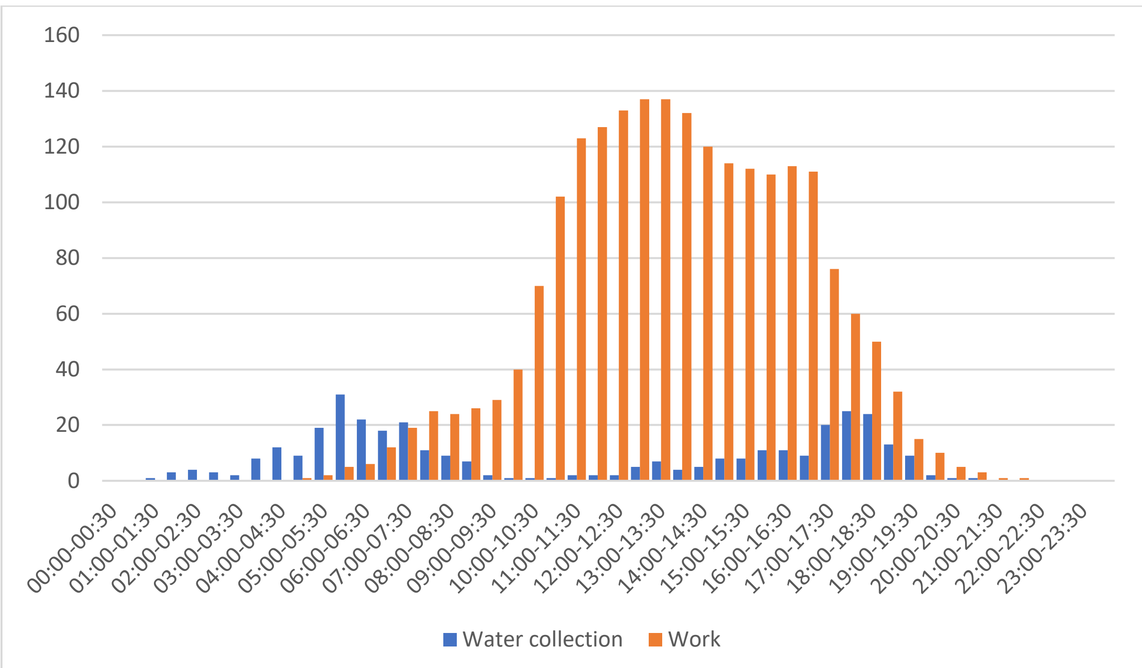
Table 3.4. Regression of time spent on water collection on the probability of employment

	Dependent variable = employed							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Activity water			−0.001***	−0.001	−0.001***	−0.001	−0.001***	−0.001
			(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)
Reliable dry			0.044	0.032				
			(0.039)	(0.043)				
Reliable rain					0.006	0.004		
					(0.038)	(0.039)		
Reliable hours							0.010	0.012
							(0.010)	(0.012)
Lnincome	0.031***	0.029***	0.031***	0.029***	0.031***	0.029***	0.034***	0.033***
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.009)	(0.009)
Household size	−0.034***	−0.034***	−0.033***	−0.033***	−0.033***	−0.033***	−0.027***	−0.030***
	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.010)	(0.009)
Age	−0.008***	−0.008***	−0.008***	−0.008***	−0.008***	−0.008***	−0.008***	−0.008***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)
Gender	−0.334***	−0.322***	−0.346***	−0.326***	−0.346***	−0.326***	−0.372***	−0.356***
	(0.039)	(0.039)	(0.039)	(0.039)	(0.039)	(0.039)	(0.047)	(0.047)
Education	−0.016	−0.005	−0.005	0.000	−0.005	−0.001	0.034	0.029
	(0.034)	(0.035)	(0.034)	(0.035)	(0.034)	(0.035)	(0.040)	(0.041)
In school	0.430***	0.381***	0.439***	0.383***	0.434***	0.381***	0.450***	0.404***
	(0.107)	(0.110)	(0.107)	(0.110)	(0.107)	(0.111)	(0.134)	(0.141)
Married	−0.034	−0.010	−0.039	−0.015	−0.036	−0.012	−0.044	−0.024
	(0.044)	(0.045)	(0.044)	(0.045)	(0.044)	(0.045)	(0.052)	(0.053)
Observations	790	790	790	790	790	790	556	556
R^2	0.137	0.176	0.148	0.179	0.147	0.178	0.157	0.186
Municipal FE	Y	N	Y	N	Y	N	Y	N
Ward FE	N	Y	N	Y	N	Y	N	Y

Notes: ***, ** and * denote significance level at 1%, 5% and 10%, respectively. Robust standard errors are in parentheses. Activities are measured in minutes/day. See Section 3 for more details on variable definitions. Employed = 1 if the individual has a valid occupation code in the household roster and is not a student/retiree/housemaker. Y, yes; N, no.

We investigated the time trade-off between work and water collection more closely by looking at the subset of participants who both worked and collected water in a typical day. Figure 5 shows the patterns of work and water collection only for the subset of those who both worked and collected water (N = 167).

Figure 3.5. Water collection time for workers. Note: This figure displays frequencies of time intervals for water collection and work for 167 (out of all 819) respondents that both worked and were the person most responsible for water collection.



Of these 167 water collectors, 26 worked right before water collection, four worked right after water collection and seven worked both before and after water collection. It is for these 37 water collectors (22% of this subsample) that time spent on collecting water was likely to directly affect the amount of time spent working. These were people who collected water in the afternoon, as shown in Figure 4 as the areas where water collection and work overlap. Of those who both worked and collected water, 41% worked in retail, 17% in other industries, 14% in government positions and 11% in wage labour. Out of 167 water collectors, 93% (N 1/4 155) were employed (which meant that they were not in school or retired). In addition, almost none of these people (less than 2%) worked as wage labourers. Water collectors are also less likely to be employed. Out of the

819 water collectors, two-thirds reported not having a full-time job (no occupation code was identified), while the proportion was only one-third of the entire sample. Hence, estimates presented in Tables 3 and 4 might be subject to selection bias as people who self-select themselves for water collection duties might have differed from the general population.

An ideal analysis would have estimated the correlation between time spent on water collection and the productive time of all household members. However, due to the restrictions of the survey, we were unable to perform this analysis. Alternatively, in Table 5, we estimate the correlation between time spent on water collection and the fraction of household members that were employed. We discovered no correlation between the two. In summary, our results suggest that for those water collectors that do work, the time they spent on productive activities were negatively correlated with time spent on water collection. However, there is limited evidence that time spent on water collection affects employment decisions.

Figure 3.6. Chores and water collection. Note: This figure displays frequencies of time intervals for water collection and non-water chores for all 819 respondents that completed the time diary in the 2014–2015 survey.

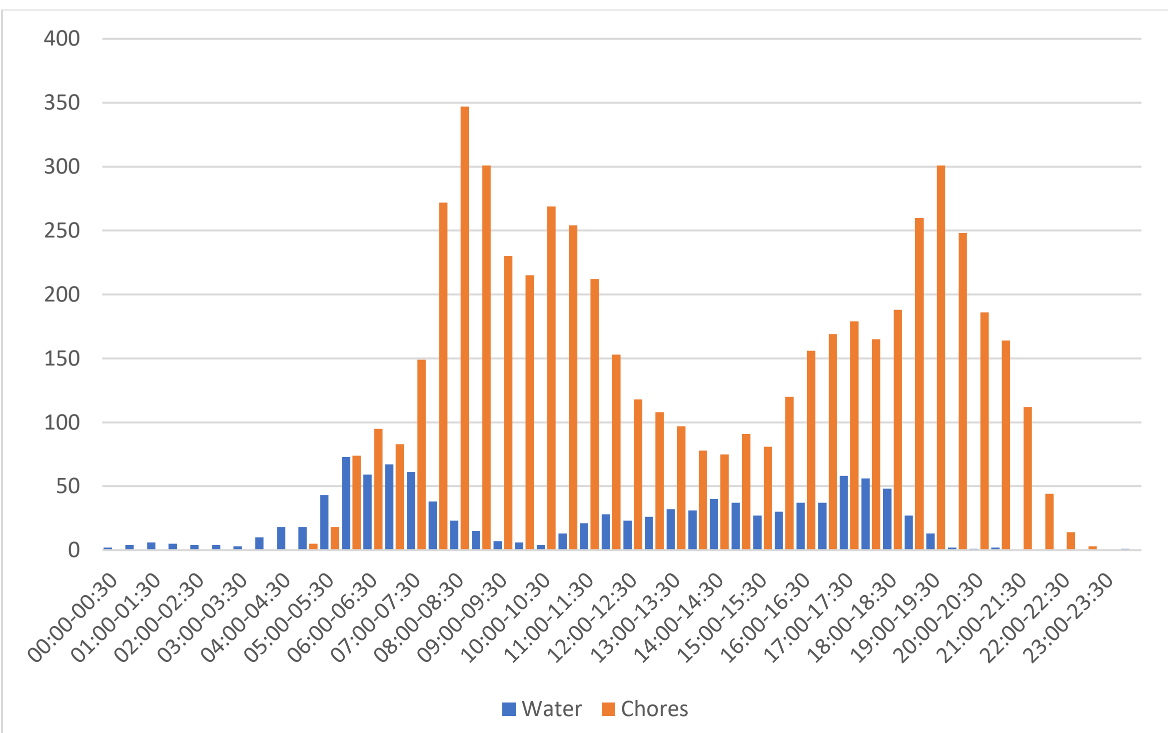


Table 3.5. Regression of time spent on water collection on the percentages of household members employment

	Dependent variable = % adult household members that are employed							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Activity water			−0.000	0.000	−0.000	0.000	−0.000	0.000
			(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Reliable dry			0.021	0.031				
			(0.020)	(0.022)				
Reliable rain					0.007	0.010		
					(0.018)	(0.019)		
Reliable hours							−0.006	−0.005
							(0.004)	(0.004)
Lnincome	0.027***	0.025***	0.027***	0.025***	0.026***	0.025***	0.029***	0.028***
	(0.005)	(0.006)	(0.005)	(0.006)	(0.005)	(0.006)	(0.006)	(0.007)
Household size	−0.016***	−0.016***	−0.016***	−0.016***	−0.016***	−0.016***	−0.017***	−0.018***
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.005)	(0.005)
Age	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Gender	−0.014	−0.007	−0.015	−0.005	−0.015	−0.005	−0.011	−0.004
	(0.020)	(0.020)	(0.020)	(0.020)	(0.021)	(0.020)	(0.024)	(0.024)
Education	−0.025	−0.020	−0.024	−0.021	−0.023	−0.021	−0.024	−0.023
	(0.016)	(0.017)	(0.016)	(0.017)	(0.016)	(0.017)	(0.020)	(0.020)
In school	0.065	0.037	0.068	0.040	0.066	0.039	0.060	0.049
	(0.054)	(0.055)	(0.055)	(0.056)	(0.054)	(0.055)	(0.070)	(0.067)
Married	−0.058**	− 0.044*	−0.060**	− 0.046*	−0.058**	− 0.043*	−0.049	− 0.033
	(0.024)	(0.025)	(0.024)	(0.025)	(0.024)	(0.025)	(0.031)	(0.032)
	(0.042)		(0.043)		(0.042)		(0.057)	
Observations	790	790	790	790	790	790	556	556
R^2	0.092	0.124	0.094	0.127	0.093	0.125	0.097	0.139
Municipal FE	Y	N	Y	N	Y	N	Y	N
Ward FE	N	Y	N	Y	N	Y	N	Y

Notes: ***, ** and * denote significance level at 1%, 5% and 10%, respectively. Robust standard errors are in parentheses. Activities are measured in minutes/day. See Section 3 for more details on variable definitions. A dependent variable is computed as the number of household members employed/ household size. Y, yes; N, no.

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3.4.3 Water Collection and Other Activities

In our time diaries, we not only asked respondents to recall the time they spent on water and work but also collected information on other activities performed throughout the day. Therefore, we had the opportunity to examine the relationship between tap water reliability and a wide range of activities, including non-water collection chores, leisure, eating meals, having tea, bathing and sleeping.

First, we examined the distribution of time spent on non-water collection chores and water collection (Figure 6). Water collection tended to occur in the morning before all other chores. Most of the chores occurred in the morning, between breakfast and lunch, when water collection activities were also low. Some water collection took place in the afternoon and increased at approximately noon, 2:00 pm and the late afternoon. Thereafter, another large portion of the chores was completed, from late afternoon through the evening. Trade-offs between water collection and other chores did not seem likely.

Figure 7 shows the time distributions for leisure and water collection. We observed significant overlaps between peak water collection times and peak leisure times, which make direct trade-offs between leisure and water collection more likely.

3.4.4 Aggregate Daily Time Use Patterns

This section of the analysis separates the households into four categories based on combinations of: if they have a private well, a PWC, and if the PWC is reliable or not. Figure 8 illustrates the proportions of the subsample that participate in each activity type during each half hour. These figures provide an idea of which activities are occurring during which times, on aggregate.

Figure 3.7. Leisure and water collection. Note: This figure displays frequencies of time intervals for water collection and leisure for all 819 respondents that completed the time diary in the 2014–2015 survey.

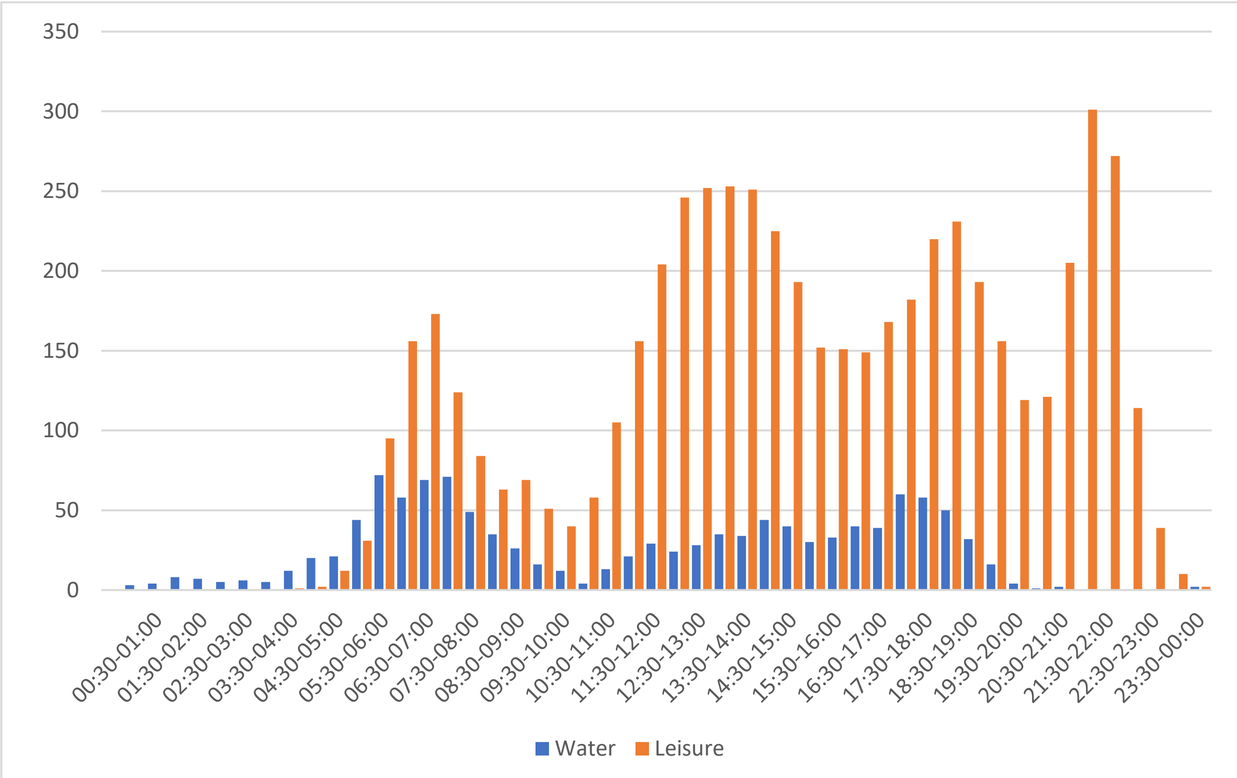

Figure 8 shows that daily time use patterns are broadly similar across the four types of households. It can be observed that water collection usually occurs in the morning or in the late afternoon. If the person most responsible for water collection was not collecting water in the morning, she or he spent time sleeping, bathing, eating meals and doing leisure activities. If water collection did not happen in the afternoon, then the person most responsible for water collection spent time reaching the end of their work day, working on other chores or engaging in leisure activities. Right before and after water collection in the evening, many households ate meals, worked on other chores and engaged in leisure activities.

Figure 3.8. Time diary. Note: These figures display aggregate daily time use patterns for households with an unreliable PWC and no private well (a), a reliable tap water connection and no private well (b), an unreliable private water connection and a private well (c) and a reliable private water connection and a private well (d).

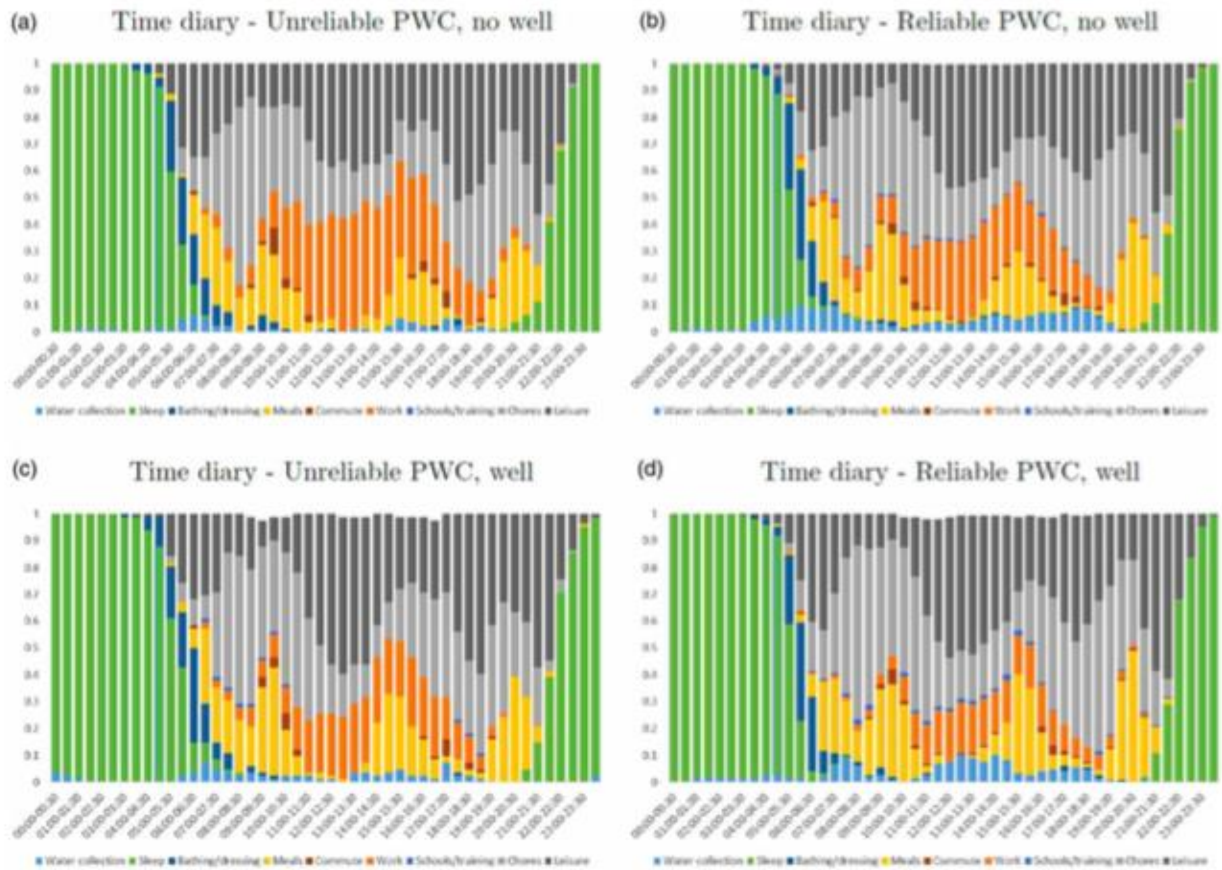

Table 3.6. Average time spent on activities by connection type (minutes/day)

Variables	Unreliable, no well	Unreliable, well	Reliable, no well	Reliable, well
Activity water	37.91	36.88	56.25	59.64
Work	148.60	121.34	122.14	115.00
School/training	2.55	5.96	5.09	11.07
Bathing/dressing	34.72	37.40	34.82	37.50
Meals	128.17	138.29	135.80	146.79
Commute	11.23	10.17	4.55	9.29
Sleep	450.13	439.83	429.38	432.14
Chores	315.32	295.17	357.32	304.64
Leisure	309.32	350.96	294.64	322.50
Observed	235	292	112	84

According to these results, it appears that water collectors in households with reliable connections spend more time on collecting water and less time working than do water collectors in households with unreliable connections. This is confirmed with average hours spent (Table 6). It shows that, interestingly, water collectors in households with unreliable connections work more than water collectors from the other subsamples (148.6 and 121.34 min per day vs. 122.14 and 115 min per day). They also spent less time on chores (315.32 and 295.17 min per day vs. 357.32 and 304.64 min per day). Households with unreliable water connections also slept more (450.13 and 439.83 min per day vs. 429.38 and 423.14 min per day). At the same time, we observed more water collectors who attend school or other training in the reliable subsamples than in the unreliable subsamples. Households with both a tap water connection and a private well spent the most amount of time on collecting water (59 min per day). Water collectors from these households also worked the least and spent more time eating meals. Water collectors from households without either a reliable tap water connection or a private well spent the least time on water collection and school/training and spent the most time sleeping and commuting compared to other household types.

Theories outlined in Section 2 provide explanation for these seemingly counterintuitive results. Regression analyses in Section 5 also confirm the descriptive findings presented here.

3.4.5 Summary of Findings

From the results, we draw three conclusions. First, households' daily time use patterns are very similar. Second, while water collection time patterns closely reflect leisure and chore time patterns, the overlap with work time in the afternoons is concerning from a policy perspective. Finally, while households with unreliable tap water connections spend the least time on collecting water, these households also purchase much more water from private vendors (tankers and jar water), suggesting that households substitute tap water with vended water.

3.5 Regression Analyses of Tap Water Reliability, Time Use and Water Consumption

3.5.1 Empirical Specification

In this section, we use ordinary least squares (OLS) regressions to estimate the correlation between time spent on water collection, water consumption and reliability of tap water in more detail. The baseline OLS regression is as follows:

$$y_{iwm} = \alpha_0 + \alpha_1 Reliability_{iwm} + \alpha_2 X_{iwm} + \alpha_3 \tau_m + \alpha_4 \sigma_w + u_{iwm}$$

where y_{iwm} are the two sets of outcomes on time allocation and water consumption as described in Section 3. $Reliability_{iwm}$ is the self-reported tap water reliability measure, which takes value 1 if it is regular and 0 otherwise, or the probability of getting tap water in the next hour. For household i, in ward w, and municipality m, X_{iwm} is a set of individual and household characteristics as observed in 2014–2015, which includes gender, education, age, age-squared, log of household income and its quadratic form and household size. We also include municipality or ward fixed effects (or both) to capture any municipality-specific or ward-specific characteristics that would affect time spent on water collection.

3.5.2 Results

Table 7 presents the OLS results of tap water reliability on time spent on collecting water and time spent on collecting water outside the household. Recall that while *activity_water* is reported by the person most responsible for water collection, *activity_water_outside* is reported by the main survey respondent. In panels A, B and C, we report the effect of three reliability measures, that is, the reliability of tap water in the dry season, in the rainy season and the probability of getting tap water in the next hour. Results in panel A indicate that greater reliability of tap water in the dry season is significantly correlated with more time spent on water collection and less time spent on water collection activities outside the household. Results in panel B demonstrate that greater reliability of tap water in the rainy season increases total time spent on water collection but is uncorrelated with time spent on water collection outside the household. Results in panel C suggest that an increase in the probability of getting tap water in the next hour is positively correlated with time spent on water collection activities and negatively correlated with water collection outside the household.

In summary, results in Table 7 suggest that more reliable tap water is positively correlated with time spent on water collection. There is also some evidence that this increase is mainly driven by time spent on collecting water from a private tap within the household.

Table 3.7. Effect of reliability on time use - OLS

Variables	(1) Activity water	(2) Activity water	(3) Activity water outside	(4) Activity water outside
Panel A				
Reliable dry	16.812*** (3.411)	7.405** (3.742)	−6.607** (2.831)	−3.421 (2.379)
N	766	766	766	766
R^2	0.107	0.284	0.151	0.102
Panel B				
Reliable rain	22.824*** (2.811)	12.160*** (2.909)	1.766 (1.663)	3.004 (2.375)
N	766	766	766	766
R^2	0.135	0.293	0.144	0.102
Panel C				
Reliable hours	1.905* (0.980)	1.113 (1.033)	−0.562*** (0.179)	−0.624** (0.273)
N	766	766	766	766
R^2	0.107	0.284	0.151	0.102
Municipal FE	Y	N	Y	N
Ward FE	N	Y	N	Y
Household controls	Y	Y	Y	Y
Individual controls	Y	Y	Y	Y

Notes: ***, ** and * denote significance level at 1%, 5% and 10%, respectively. Robust standard errors are in parentheses. Each cell reports the coefficient from a separate regression. Activities are measured in minutes/day. See Section 3 for more details on variable definitions. All regressions control for log household income, household size, individual age, gender, education, whether in school and marital status. Y, yes; N, no.

Table 8 shows the effect of tap water reliability on water consumption. Similar to the previous table, we group results into four panels with respect to the three reliability measures. Panels A and B report the effect of reliability in the dry season and the rainy season on water consumption in dry and rainy seasons, respectively. Panels C and D report the effect of '*reliable_hrs*' on water consumption in dry and rainy seasons, respectively. Column (1) shows a positive and significant correlation between reliability and total water consumption for three out of the four reliability measures when municipality fixed effects are included. In column (2), the probability of getting water in the next hour was still positively correlated with total water consumption when ward fixed effects are controlled for. The magnitude of coefficients in panel C suggests that a 1 percentage point increase in the likelihood of receiving water in the next hour leads to 47.5 more litres of total water consumption per day. Columns (3)–(10) present the results for each water source. As columns (3) and (4) indicate, unsurprisingly, reliability of tap water is associated with more water consumption from the private tap. These results are significant with or without the ward fixed effects. Results in columns (5)–(10) suggest substitution of consumption between water received from the tap and that from other sources. Furthermore, tap water reliability is negatively associated with water consumed from a private well, public tap (or stone tap) or from water vendors.

Table 3.8. Effect of reliability on water consumption - OLS

Variables	(1) Water total	(2) Water total	(3) Water pipe	(4) Water pipe	(5) Water public	(6) Water public	(7) Water priwell	(8) Water priwell	(9) Water vendor	(10) Water vendor
Panel A										
Reliable dry	60.538**	−22.641	122.607***	79.474***	−17.716***	−3.624	−10.956	−69.339***	−29.138***	−25.849*
	(27.713)	(31.040)	(17.206)	(17.274)	(4.090)	(3.947)	(22.885)	(25.294)	(9.503)	(13.585)
N	766	766	766	766	766	766	766	766	766	766
R^2	0.128	0.273	0.179	0.238	0.196	0.233	0.101	0.300	0.051	0.089
Panel B										
Reliable rain	42.567	−39.219	120.961***	64.537***	2.753	8.116*	−47.430	−79.885***	−29.205***	−33.001***
	(33.630)	(28.466)	(16.342)	(17.727)	(3.657)	(4.285)	(29.677)	(24.434)	(7.902)	(8.430)
N	766	766	766	766	766	766	766	766	766	766
R^2	0.129	0.298	0.117	0.223	0.184	0.285	0.095	0.296	0.068	0.099
Panel C										
Reliable hours (dry)	36.603**	34.918**	27.647***	22.379**	−1.662***	−1.140*	8.625	11.757	2.661	2.411
	(14.709)	(14.440)	(10.335)	(10.063)	(0.510)	(0.597)	(8.671)	(7.962)	(6.752)	(6.167)
N	542	542	542	542	542	542	542	542	542	542
R^2	0.130	0.320	0.154	0.341	0.125	0.315	0.090	0.300	0.047	0.088
Panel D										
Reliable hours (rain)	66.104***	57.141***	67.267***	53.079***	−1.856***	−1.127**	3.812	7.617	−1.736	−1.860
	(20.077)	(19.236)	(17.872)	(16.490)	(0.493)	(0.535)	(7.214)	(6.607)	(2.632)	(2.575)
N	542	542	542	542	542	542	542	542	542	542
R^2	0.171	0.392	0.235	0.406	0.156	0.408	0.076	0.301	0.066	0.090
Municipal FE	Y	N	Y	N	Y	N	Y	N	Y	N
Ward FE	N	Y	N	Y	N	Y	N	Y	N	Y
Household controls	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Individual controls	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

Notes: ***, ** and * denote significance level at 1%, 5% and 10%, respectively. Robust standard errors are in parentheses. Each cell reports the coefficient from a separate regression. Activities are measured in minutes/day. See Section 3 for more details on variable definitions. Panel C estimates the effect of reliable hours on dry season water consumption. Panel D estimates the effect of reliable hours on rainy season water consumption. All regressions control for log household income, household size, individual age, gender, education, whether in school and marital status. Y, yes; N, no.

Table 3.9. Robustness checks – adding more control variables

Dependent variables	(1) Activity water	(2) Activity water	(3) Activity water outside	(4) Activity water outside	(5) Water total	(6) Water total	(7) Water pipe	(8) Water pipe
Panel A								
Reliable dry	16.593***	6.136*	−7.398***	−4.046**	62.930**	−27.188	122.006***	79.622***
	(3.258)	(3.685)	(2.433)	(1.970)	(26.617)	(30.470)	(15.880)	(16.205)
N	819	819	819	819	819	819	819	819
R^2	0.085	0.255	0.102	0.068	0.072	0.228	0.156	0.208
Panel B								
Reliable rain	23.260***	12.176***	2.966* (1.754)	5.229* (2.866)	38.742	−50.418*	119.722***	60.933***
	(2.679)	(2.818)			(32.969)	(28.565)	(16.112)	(16.832)
N	819	819	819	819	819	819	819	819
R^2	0.117	0.266	0.096	0.070	0.084	0.255	0.096	0.190
Panel C								
Reliable hours (dry)	1.980**	1.068 (1.006)	−0.504***	−0.558**	42.231***	38.723**	28.821***	23.089**
	(0.979)		(0.164)	(0.249)	(15.737)	(15.121)	(10.309)	(9.927)
N	575	575	575	575	575	575	575	575
R^2	0.099	0.294	0.108	0.086	0.084	0.279	0.134	0.344
Panel D								
Reliable hours (rain)					72.435***	61.018***	70.629***	55.251***
					(20.847)	(19.688)	(18.064)	(16.522)
N					575	575	575	575
R^2					0.141	0.363	0.226	0.406
Municipal FE	Y	N	Y	N	Y	N	Y	N
Ward FE	N	Y	N	Y	N	Y	N	Y
Household and individual controls	Y	Y	Y	Y	Y	Y	Y	Y
Additional controls	Y	Y	Y	Y	Y	Y	Y	Y

Notes: ***, ** and * denote significance level at 1%, 5% and 10%, respectively. Robust standard errors are in parentheses. Each cell reports the coefficient from a separate regression. Activities are measured in minutes/day. See Section 3 for more details on variable definitions. All regressions control for log household income, household size, individual age, gender, education, whether in school and marital status. In addition, we also control for age square, gender of head of household and survey month.

Columns (1)–(4) of panel D are left blank purposely as these coefficients are the same as columns (1)–(4) in panel C. Columns (5)–(8) in panel C estimate the effect of reliable hours on dry season water consumption. Columns (5)–(8) in panel D estimate the effect of reliable hours on rainy season water consumption. Y, yes; N, no.

Table 3.10. Robustness checks – drop observations surveyed in August

Table 10. Robustness checks – drop observations surveyed in August.

Dependent variables	(1) Activity water	(2) Activity water	(3) Activity water outside	(4) Activity water outside	(5) Water total	(6) Water total	(7) Water pipe	(8) Water pipe
Panel A								
Reliable dry	18.442***	6.806	−2.746 (1.960)	−3.167* (1.855)	34.699	0.064	119.274***	85.893***
	(3.932)	(4.562)			(28.386)	(33.337)	(21.009)	(22.447)
N	556	556	556	556	556	556	556	556
R^2	0.115	0.329	0.218	0.103	0.083	0.216	0.180	0.222
Panel B								
Reliable hours (dry)	3.176**	1.099	−0.658***	−0.311**	63.703***	50.154**	39.407***	33.286**
	(1.412)	(1.564)	(0.183)	(0.143)	(19.813)	(20.165)	(12.862)	(14.070)
N	387	387	387	387	387	387	387	387
R^2	0.145	0.360	0.121	0.157	0.158	0.277	0.222	0.378
Municipal FE	Y	N	Y	N	Y	N	Y	N
Ward FE	N	Y	N	Y	N	Y	N	Y
Household and individual controls	Y	Y	Y	Y	Y	Y	Y	Y
Additional controls	Y	Y	Y	Y	Y	Y	Y	Y

Notes: ***, ** and * denote significance level at 1%, 5% and 10%, respectively. Robust standard errors are in parentheses. Each cell reports the coefficient from a separate regression. Activities are measured in minutes/day. See Section 3 for more details on variable definitions. We only report the effect of reliability in dry seasons in this table as all samples included in this table are surveyed in the dry season. All regressions control for log household income, household size, individual age, gender, education, whether in school and marital status. Y, yes; N, no.

3.6 Robustness Checks

We conducted two robustness checks to confirm whether our results were sensitive to the choice of control variables and sample selection. Results are presented in Tables 9 and 10.

Table 9 presents our results after we re-run our OLS regressions by adding more household control variables, including age square, survey month and gender of the household head. Each cell in the table is a separate regression, and we report coefficients for *reliable_dry*, *reliable_rain* and *reliable_hrs* in panels A, B, C and D. Columns (1)–(4) of panel D are intentionally left blank as these coefficients are the same as columns (1)–(4) in panel C. Columns (5)–(8) in panel C estimate the effect of '*reliable_hrs'* on water consumption in the dry season. Columns (5)–(8) in panel D estimate its effect on water consumption in the rainy season. We reported both results with municipal fixed effects or ward fixed effects. As observed, with these additional controls, our main results were largely consistent other than the effect of *reliable_rain* on total water consumption in column (6). When ward fixed effect was controlled for, the effect was negative and statistically significant. A possible explanation is that households without reliable tap water might store extra water or over-consume during the rainy season when water is relatively cheap, while consumption decisions are less affected for households with reliable tap water.

Table 10 presents the results when households surveyed in August are excluded. We performed this analysis in August as it is typically the last month of the rainy season in the Kathmandu Valley. By retaining results for dry season water consumption and dry season reliability, we sought to reduce potential recall errors due to the timing of survey. We ran the regressions again using the main specification, and the results were similar.

3.7 Conclusion

In this paper, we analysed the relationship between household time allocation, reliability of tap water and water consumption patterns under conditions of intermittent supply. We discover that time spent on productive activities is negatively correlated with time spent on water collection for the person most responsible for water collection in the household. We also demonstrate that when tap water connections become more reliable, households spend more time on collecting water. As a consequence of this time investment, households consume more water both from their private tap and overall.

From a policy perspective, because an increase in reliability leads to an increase in collection time inside the home, it is important to arrange water supply schedules in a way that minimises disruptions that can affect work, leisure and other activities. For cities with intermittent supply, more research is needed to understand how individuals and households prioritise different activities in order to identify which times of day would be the most conducive to water collection. Additionally, since we were unable to record simultaneous activities within the same time block, it may be relevant to determine what other activities occur while the tap is turned on and the water collector is waiting for the storage containers to be filled. Finally, with households with unreliable water connections shifting away from collecting water outside the home to vended water, there is room to examine the trade-offs between collecting and buying water.

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CHAPTER 4: HOUSEHOLDS' PREFERENCES FOR WATER TARIFF STRUCTURES IN KATHMANDU, NEPAL[6]

4.1 Introduction

Water utility managers, their tariff consultants, and regulators rarely consult a utility's customers about the form of tariff structure households would prefer. Both citizens and water utility managers pay a great deal of attention to changes in fixed charges and volumetric prices charged to customers, but much less attention to customers' preferences for the tariff structure itself. Water tariff design is typically assumed to be best left to experts who can most appropriately balance the utility's objectives of cost recovery and revenue stability with their customers' objectives of equity, fairness, affordability, and economic efficiency.

Because in most locations water utilities operate as monopoly suppliers of piped water and sewer services, their tariff structures are effectively administered prices, and utility customers have few opportunities to reveal their preferences for alternative pricing structures.[7] As a result, there can be a serious mismatch between the water tariff structure used and household preferences for the tariff structure. Unpopular tariff structures can have a long life because customers have no easy way to drive them out of the market. This is quite different, for example, from the telecommunications sector where competition can be intense. Mobile phone companies are consistently offering customers a variety of different rate plans from which they can choose, and unpopular rate plans quickly disappear from the market.

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[7] In Scotland, some households are now able to choose their bulk water supplier, but globally this is very rare.

There is a sizeable consulting business in the preparation of tariff studies for water utilities, and there is near global consensus among water utility managers and international donors that increasing block tariffs (IBTs) are the tariff structure best suited to balancing the multiple objectives of tariff design, and ensuring that poor households have access to sufficient quantities of water at affordable prices. Consultants specializing in advising water utilities on water tariff structures and price levels typically assume that an IBT should be used, and then discuss with utility management the pros and cons of such issues as the number and size of blocks, the size of any positive fixed charges, minimum monthly water bills, and seasonal pricing.

Numerous scholars, however, have challenged this global consensus on IBTs, arguing that IBTs neither target subsidies to poor households effectively nor send the correct signals about the economic value of water (Boland & Whittington, 2000; Foster & Araujo, 2004; Komives et al., 2007; Diakité et al., 2009; Angel-Urdinola & Wodon, 2012; Whittington et al., 2015; Fuente et al., 2016; Nauges & Whittington, 2017). Given this debate between scholars and practitioners over the efficiency and effectiveness of IBTs, it is timely to ask what households themselves think. In fact, utilities rarely elicit input from households on tariff design issues. In some countries, public hearings might be held to gauge citizens' reactions to specific proposals from tariff consultants, but such input is often sought after the main tariff design issues have already been decided.

There are several reasons that household preferences should be considered in the selection of a water tariff structure. First, households may have a preference for a specific water tariff structure, and the utility's choice of tariff structure may affect their well-being. From a cost–benefit perspective, ignoring household preferences will miss an opportunity to increase welfare. Second, households are probably more likely to pay water bills and to support a water utility that uses a tariff structure that they believe is fair and efficient. Perceptions of fairness are important for the cooperation of households with an institution (Pokharel, 2015). Third, many households likely believe that they have a right to have their voices heard in matters of pricing such basic services as water. Ignoring household preferences on the tariff structure deployed may expose water utilities and policy-makers to greater political risks (Crase et al., 2008).

Water tariff structures are often designed based on certain assumptions about household behaviors and how such behaviors may be altered by price mechanisms. Such assumptions should be based on a careful investigation of households' preferences. For example, IBTs are often proposed based on the assumption that they will provide the right 'price signal' to consumers. In fact, this marginal price signal can only be provided to households in one of the blocks of the IBT (most likely the highest price block).

In this paper we report the results from a survey conducted in 2014 of 1,500 households in Kathmandu, Nepal, in which we asked respondents for their opinions about different water tariff structures. Specifically, we asked households about their preferences regarding three attributes of a water tariff: (1) its structure (IBT vs uniform volumetric pricing); (2) positive fixed charges; and (3) household flexibility in selecting rate plans. We collected information on households' knowledge, attitudes, and perceptions about the water services in Kathmandu; and households' urban environmental and infra structure priorities. We also asked respondents what they thought a 'fair water bill' would be for a randomly assigned fixed quantity of water. We analyzed these answers to determine whether respondents had a preference for increasing nonlinear tariff structures. We find that respondents support monthly water bills that increase linearly as the quantity of water use increases.

In the next section of the paper, we summarize the prevalence of different tariff structures being used globally and then present the tariff structure currently used in Kathmandu. The third section describes our fieldwork in Kathmandu and provides a socioeconomic profile of our sample respondents. The fourth section describes our analytical strategy. In the fifth section we present the results. We first describe households' knowledge, attitudes, and perceptions about the water supply in Kathmandu, and the priority they place on reducing water shortages compared to other urban problems. We then present our results regarding households' preferences for different attributes of water tariff structures, as well as regression analyses that examine the types of households that prefer different tariff structures. The sixth section summarizes our results and offers concluding remarks.

4.2 Background

Most water utilities globally now use IBTs to calculate customers' water bills. The Global Water Intelligence (GWI) database reported 122 out of 165 selected utilities from around the world were using IBTs in 2013. China had been one of the last refuges of uniform volumetric tariffs, but in 2013, the Chinese government mandated that all cities in China must adopt IBTs by the end of 2015 (National Development and Reform Commission, 2013). The predominance of IBTs globally can be expected to grow as Chinese cities make the shift to IBTs over the next few years.

Although there is a clear preference for the basic IBT structure, there is no consensus on the details. IBTs have four main features: (1) number of blocks; (2) size of the blocks, especially the first ('lifeline') block; (3) presence and size of a positive fixed charge; and (4) the volumetric prices charged in each block. Tariff consultants and utility managers argue over these features, and there is wide variation across all four globally.

For example, the number of blocks in the IBTs in the GWI database varies widely. Of the 122 IBTs, the most common number of blocks was three (28%), followed by four blocks (21%). However, 6% had two blocks, 11% had five blocks, 10% had six blocks, 7% had seven blocks, and 18% had eight blocks.

The GWI database also reports sizes of the first (lifeline) block for the IBTs. The median size is 10 m^3 in East Asia, South Asia, and Latin America, and somewhat lower in North and sub-Saharan Africa (8 and 7 m^3 per month, respectively), but the standard deviation is large. With such large lifeline blocks, it is not usual for some utilities to have a large proportion, even a majority, of their residential consumers falling into the lifeline block.

Positive fixed charges raise the average price paid by small volume-using households more than that of large volume-using households and thus penalize the same households that the IBT's lifeline block is designed to help. Nevertheless, most water utilities in the GWI database that use IBTs (70%) add a positive fixed charge to the volumetric component of their customers' water bills. The mean positive fixed charge was US$4.35 per month. Only 30% of utilities with uniform volumetric tariffs add a fixed charge, and their average fixed charge is lower (US$3.20 per month),[8] which suggests that more of these uniform tariff-setting utilities may be aware of the adverse effect of fixed charges on poor households.

One would expect volumetric prices in different blocks to vary across utilities due to differences in the costs of water and wastewater services, and the differences are indeed substantial. However, across all of the IBT structures, volumetric prices are very low in all of the blocks (not just the lifeline block). Considering only the 34 IBTs with three blocks (the most common IBT in the GWI database), the median volumetric price was US$0.35 per cubic meter in the first block, US$0.57 per cubic meter in the second block, and US$0.75 per cubic meter in the third block.

Most water utilities subsidize water use, and the average cost of water supply is more than the price in the highest-price block. Thus, the more water a household uses, the higher the subsidy it receives (Nauges & Whittington, 2017).

4.3 Kathmandu Case Study

The Kathmandu water utility (Kathmandu Upatyaka Khanepani Limited, KUKL) uses an IBT with a minimum bill. KUKL currently has about 190,000 residential customers (KUKL, 2015). The water bills of households with both metered and unmetered connections to the pipe network are calculated based on the pipe size of their connection. Most connected households have a half-inch

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[8] The median positive fixed charges in East Asia (US$5) and Latin America (US$4 per month) are much higher than those in sub-Saharan Africa, the Middle East, North Africa, and South Asia (all about US$1 per month).

pipe connection. Households with a metered one-half inch pipe connection are charged 100 NPR (US$0.96) for the first 10 cubic meters. For additional water use above the minimum 10 cubic meters, a household is charged 32 NPR (US$0.31) per cubic meter. For example, a household with a metered half-inch pipe connection that used 18 cubic meters a month would receive a water bill of 356 NPR (100 NPR for the first 10 cubic meters plus 32 NPR per cubic meter for the subsequent 8 cubic meters). Households with half-inch, unmetered connections are charged 785 NPR (US$7.50) per month.

This tariff structure has the appearance of an IBT because, if the household uses all 10 cubic meters, its average price is just 10 NPR (≈US$0.10) per cubic meter, and for additional water use the price is 32 NPR per cubic meter. However, the minimum bill of 100 NPR means that the marginal price for additional water use within the 'lifeline' block of 10 cubic meters is effectively zero because households must pay this minimum charge regardless of how much water they use (e.g., they are charged the same 100 NPR whether they use 5, 7, or 10 cubic meters).

The implementation of an infrastructure investment program (the Melamchi Water Supply Project) is now underway. When completed, it will provide a new raw water supply for the Kathmandu Valley, and improvements in both the water and wastewater networks, as well as wastewater treatment facilities. Donor support for this project had been conditional upon tariff reform, and originally consultants had estimated that a 13-fold increase of the water tariff would be required between 1999 and 2009 to meet operating costs of the water network (Domènech et al., 2013). The revised 2009 tariff increased the tariff set in 2004 by 10–30%, depending on the amount consumed (Himalayan Times, 2009; ADB, 2013). It included a lifeline block, but NGOs deemed this insufficient to assist poor households and demanded targeted subsidies for the poor (Gutierrez et al., 2003; Domènech et al., 2013). A new tariff structure was introduced in 2013, which increased the average tariff by 82%. This price increase, however, was still not enough to cover operating and maintenance costs, service charges, and debt (ADB, 2015). Further changes in the current tariff structure are thus a possibility, and our questions about tariff preferences were highly salient to sample respondents.

4.4 Fieldwork and Socioeconomic Profile of Sample Respondents

Our survey of 1,500 households was conducted in five municipalities in the Kathmandu Valley (Kathmandu, Lalitpur, Bhaktapur, Kirtipur, and Madhyapur) from August to October 2014. Households in this 2014 survey were selected based on a 2001 sample that was drawn to be representative of the population of Kathmandu at the time (Gurung et al., 2017). We chose to re-interview the households from 2001 in order to construct a panel dataset. The sample is thus not representative of the 2014 population of households (differences are reported in the Appendix, Table B.1). In 2001, households were selected using a multi-stage clustered sampling procedure (see Whittington et al. (2002) and Pattanayak et al. (2005) for more details). In the 2014 re-survey of the 2001 households, if we were unable to locate the original household, a nearby household in the same cluster was selected for an interview.[9] In total, we were able to locate and re-interview 927 of the 1,500 households in the 2001 survey. In the 2014 survey, there are thus 573 replacement households.[10]

[9]If the household head from the 2001 sample household was missing, the next most senior member of the house was interviewed.

[10]Although the 2001 households were a representative sample of the population in the five municipalities in Kathmandu Valley, the sample from the 2014 re-survey is not because many households migrated to Kathmandu over the period from 2001 to 2014. These households are not part of our 2014 sample unless they happened to be included as a replacement household. Appendix Table B.1 shows that the survey households are more likely to be homeowners, to use LP gas as the cooking fuel, to have a flush toilet connected to the sewer systems, to own more durable goods, and are more likely to be literate in Kathmandu and Lalitpur.

Table 4.1. Socioeconomic profile of sample households

Variable	N	Median	Mean	SD
Monthly household income	1,500	57,500	70,441	74,299
Household size	1,500	5	5.05	2.12
Head of household age	1,500	56	56.52	12.86
Electricity	1,500	1	1.00	0.05
Landline	1,500	1	0.64	0.48
Number of cellphones	1,495	3	3.20	1.64
Electricity bill	1,476	700	897	749
Phone bill	1,500	1,000	1,288	1,178

Table 1 presents a socioeconomic profile of the sample households. As shown, monthly mean household income was 70,441 NPR (about US$700). The average household size was five members. The average age of the head of household was 57 years (reflecting the sampling strategy of re-surveying the 2001 sample). Table 1 also reports summary statistics on infrastructure services and housing. Virtually every household in the sample had electricity (99.7%) and some sort of access to the telecommunications network (98%), either via a landline (64%) or a cellphone. Households had, on average, three cellphones. Mean monthly phone bills were 1,288 NPR (US$13), about 2% of monthly income. Average monthly electricity bills were 897 NPR (US$9), about 1% of monthly income.

Table 4.2. Piped water summary statistics

	N	Median	Mean	SD
Private water connection (1 = yes, 0 = no)	1,500	1	0.70	0.46
Water use – rainy season (L/day)	1,046	143	240	329
Water use – dry season (L/day)	988	75	126	183
Days between service	1,051	5	4.99	2.93
Length of service each time water comes (min)	1,050	60	98.6	84.2
Hours of service per month	1,050	7.5	11.5	14.2
Water meter (1 = yes, 0 = no)	1,500	1	0.63	0.48
Working water meter (1 = yes, 0 = no)	1,500	1	0.59	0.49
Received water bill (1 = yes, 0 = no)	1,500	1	0.67	0.47
Monthly water bill	1,051	150	218	229
Average price paid for water from the piped connection (NPR/m^3)	988	71	170	337

Table 2 presents some quantitative characteristics of the piped water system, as reported by our respondents. Seventy per cent of the sample households had a private water connection. Households with private connections reported that they received very little water from their connection during the dry season (median and mean are 75 and 126 L/household/day, respectively), and about twice that during the rainy season (median and mean of 143 and 240 L/household/day, respectively). Households received water from their private connections for only about an hour to an hour and a half, on average, once every 5 days. Most households (59%) reported having a working water meter, and 67% received a water bill (a large majority reporting receiving their bill monthly). The median monthly bill of a household was 150 NPR (US$1.55), with a mean water bill of 218 NPR (US$2.25), 0.5% of monthly household income. The average price paid for the water from a private connection was 170 NPR per m^3 (US$1.75 per m^3); the median price was 71 NPR per m^3 (US$0.73 per m^3).

4.5 Analytical Strategy for Investigating Households' Preferences for Water Tariff Structures

We examine households' preferences for different tariff structures in two ways. First, we asked respondents a series of direct questions. Enumerators explained to each of the households in the 2014 survey how water bills are calculated when a water utility uses either a uniform volumetric tariff or an IBT. Respondents were not given specific volumetric prices for the two tariff structures, or other details about the IBT structure, such as the number and size of blocks.

Respondents were then asked which tariff structure they would prefer the water utility to adopt and the reasons why they selected their preferred tariff structure. Enumerators next asked respondents whether their choice of tariff structure was based on whether it was best for their household or all the households in Kathmandu.

Enumerators also explained that many water utilities used a two-part tariff that added a positive fixed charge to the volumetric component to calculate customers' water bills. Respondents were asked if they thought the use of a positive fixed charge was a good idea. Next, enumerators reminded respondents that mobile phone customers could choose the rate plan (tariff structure) that best suited their household. Enumerators asked respondents if they would like to be able to choose their tariff structure for piped water and wastewater services (even if the respondent's household did not have a piped connection).

We checked respondents' understanding of the IBT concept. Those who did not pass the check question (e.g., 'IBT means that the price per unit of water will increase in stages as a household's total water use increases. True or False?') are not included in all parts of the analysis (N = 271 from 1,500 households). Understanding of the IBT concept is most critical for the choice between an IBT and uniform volumetric tariff structure; it is not as important for respondents' choice of a fixed charge.[11]

The propensity to select an IBT and the propensity to select a fixed charge are both dichotomous variables. Therefore, a latent variable model is used to examine their relationships with each other and socioeconomic factors, water use, and other preferences. Because these decision variables could be connected, unobservable variables may affect both the propensity to choose an IBT and a fixed charge. The seemingly unrelated probit model jointly estimates these two propensities with their disturbances (Greene, 2011). We test for exogeneity using maximum-likelihood simultaneous estimation of the two probit equations, i.e., recursive bivariate probit (Maddala, 1983; Costa-Font & Gil, 2005). This model allows us to correct for some of the unobserved heterogeneity that can contribute to omitted variable bias and is also expected to increase the efficiency of the estimation (Costa-Font & Gil, 2005; Greene, 2011).

The specification for our two-equation model is as follows:

[11] Appendix Table B.2 shows the differences between these two sub-samples. Respondents who responded 'not sure' or 'do not know' are also excluded (N ¼ 22). A selection model was considered but the likelihood ratio test of independent equations failed to be rejected, suggesting there is no selection bias due to a respondent initially failing to pass the check question.

$$IBT_i^* = \beta_0 + \beta_1 SE_{1i} + \varepsilon_{1i}, IBT_i = 1 \; if \; IBT_i^* > 0, 0 \; otherwise, \tag{1}$$

$$Fixed_i^* = \delta_0 + \delta_1 SE_{2i} + \varepsilon_{2i}, Fixed_i = 1 \; if \; Fixed_i^* > 0, 0 \; otherwise, \tag{2}$$

$$\begin{pmatrix} \varepsilon_{1i} \\ \varepsilon_{2i} \end{pmatrix} | SE_{1i}, SE_{2i} \Big) \sim N\left[\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} 1 & \rho \\ \rho & 1 \end{pmatrix}\right].$$

where IBT_i = binary indicator for household i's stated preference for a uniform volumetric or IBT, $Fixed_i$ = binary indicator for household i's stated preference for a fixed charge, SE_{1i}, SE_{2i} = vector of socioeconomic characteristics of household i, $\varepsilon_{1i}, \varepsilon_{2i}$ = random error terms.

IBT_i^*, $Fixed_i^*$ are latent variables observed as dummy variables IBT_i, $Fixed_i$, respectively. SE_{1i}, SE_{2i} are exogenous variables, and $\beta_0, \beta_1, \delta_0, \delta_1$ are parameters of the preference functions. The error terms of the two equations are modeled to be dependent and distributed as a bivariate normal. The Wald test for $\rho = 0$ provides evidence about the correlation between the error terms of the equations and if the models should therefore be jointly estimated.

Second, in a different section of the questionnaire, households were also asked the following question:

> *After the Melamchi water supply project is completed, households with piped water connections will have better service. What do you think a fair[12] monthly water bill would be for a household that uses [5000, 10000, 15,000, 20,000, 25,000, 30,000] liters per month?*

The different quantities of monthly water use (5,000, 10,000, 15,000, 20,000, 25,000, 30,000 liters per month; or 5, 10, 15, 20, 25, 30 m^3 per month) were randomly assigned to sample respondents. Each respondent answered this question only once for the single randomly assigned quantity that they received. We estimated the relationship between the respondent's reported 'fair monthly

[12] We note that there is no direct translation for the word 'fair' in Nepali. There are two closely related words in Nepali that reflect two closely related concepts – fairness in process and fairness in outcome (Pokharel, 2015). However, these concepts do not apply precisely to the task of expressing a single estimate for a 'fair' water bill associated with a specified quantity of water. However, we believe that respondents' answers to the question posed reflect an understanding of the English meaning of 'fair water bill'.

water bill,' the exogenously assigned quantity and socioeconomic covariates of the respondent's household socioeconomic characteristics using the following equation:

$$WaterBill_i = \beta_0 + \beta_1 Q_i + \beta_2 (Q_{ij})^2 + \beta_3 SE_i + \varepsilon \quad (3)$$

where $WaterBill_i$ = self-reported fair water bill of household i, $Q_{i,j}$ = quantity of water j randomly assigned to household i (j = 5,000, 10,000, 15,000, 20,000, 25,000, 30,000 liters per month), SE_i = vector of socioeconomic characteristics of household i.

We expect that respondents, in aggregate, believe it would be fair for a household that uses more water to pay a higher water bill, so $\beta_1 > 0$. We are agnostic about the sign and significance of β_2. If respondents, in aggregate, believe that a household that uses more water should pay an increasingly higher water bill, then $\beta_2 > 0$. For example, if households favor an IBT or other form of increasing non linear tariff structure, then we expect $\beta_2 > 0$. Similarly, if households favor a decreasing block or other decreasing nonlinear tariff structure, $\beta_2 < 0$. If households favor a uniform volumetric tariff, we expect β_1 to be positive, but for β_2 not to be statistically significant.

This model describes aggregated household preferences. Households were not asked to state fair monthly water bills for multiple hypothetical quantities, so we cannot use these data to test whether the respondent understood how the household's water bill would be calculated if an IBT were used. Even if all households preferred and understood an IBT, they may still disagree on sizes and prices of blocks, and thus β_1 and β_s might not necessarily be significant and/or positive.

For all three models, fixed effects at the municipality level are included. Standard errors are clustered at the neighborhood level.

4.6 Results

4.6.1 Salience of the Water Supply Situation in Kathmandu

We first demonstrate that the water shortage in Kathmandu was highly salient to sample respondents. Table 3 reports respondents' answers to a question that asked their first, second, and third priorities from a predetermined list of environmental and infrastructure problems.

Respondents were most concerned about three urban infrastructure problems: (1) water shortage, (2) electricity outages, and (3) poor garbage collection and solid waste management. Of these three, addressing the water shortage was overwhelmingly respondents' top priority.

Table 4.3. Urban environmental and infrastructure priorities*

	First	Second	Third
Water shortage	57%	21%	9%
Electricity outage	14%	39%	23%
Air pollution	9%	5%	10%
Poor garbage collection and solid waste	8%	15%	27%
Contamination of drinking water	6%	7%	9%
Poor sewerage	5%	8%	9%
Improper disposal of hazardous wastes	1%	1%	2%
Water pollution in rivers	1%	2%	5%
Poor drainage/flooding	0%	2%	2%
Too much noise	0%	1%	2%

*Survey question: Which one of these environmental problems is the [first/second/third] most important that the government should solve in this city?

This conclusion is reinforced by respondents' answers to another question in the survey. We told respondents in households with and without private connections to:

> *'... Suppose that you are able to have potable water from a private connection and the water service is available several hours per day, seven days per week, and that your monthly water bill will be equal to or less than what you are currently paying for water from all sources. In which of the following areas would you like to adjust your water use: drinking, cooking, bathing, cleaning house, outdoor gardening?'*

The closed-end answers were, 'increased a little,' 'increased substantially' and 'no change.' Table 4 shows that the majority of respondents expect that their household's water use would increase a little or substantially for three large components of household water uses: bathing, cleaning house, and outdoor gardening.

Table 4.4. Anticipated changes in water use after completion of Melamchi Project (number of respondents)

	Increase a little	Increase substantially	No change
1. Drinking	234	31	1,235
2. Cooking	409	55	1,036
3. Bathing	808	309	383
4. Cleaning house	820	318	362
5. Outdoor gardening	765	290	445
6. Washing clothes	53	32	1,415

4.6.2 Preferences for IBT vs Uniform Volumetric, Fixed Charges, Tariff Flexibility at the Household Level

We next examine reported preferences for tariff structures, fixed charges, and tariff flexibility at the household level. We also examine water infrastructure and socioeconomic characteristics of households that are associated with their tariff preferences. We first report the descriptive statistics and then the results of our probit models.

Table 5 compares the characteristics of households who prefer the IBT to a uniform volumetric rate. Fifty-eight percent of households (705 households) expressed a preference for the IBT compared to the uniform volumetric tariff (505 households). Twenty-five per cent of those who preferred the IBT also preferred a positive fixed charge. Most of those who prefer a uniform volumetric tariff (59%) also prefer a positive fixed charge. Additionally, 70% of all households preferred to have some choice of their water tariff structure.

Table 4.5. Household tariff preferences

	Preferred IBT	Preferred uniform volumetric tariff	Total
Tariff choice (number of households)	705	505	1,210
Preferred positive fixed charge	25%	59%	39%
Tariff flexibility	70%	70%	70%
Considered other households in Kathmandu in tariff choice	84%	70%	78%
Current water use from tap (m^3/month)	1.67	2.82	2.15
Reasons for tariff choice	My household gets a discount if we use less water (42%)	Same price rate for all customers (42%)	
	People who consume more water should pay higher prices for the extra water they consume (30%)	Encourages water conservation (21%)	
	Encourages water conservation (18%)	Cost of supplying water is the same so price should be the same (20%)	
	Helps poor households (10%)	Easy to calculate expenses on piped water (13%)	
What do you like least about the service from the piped water connection?	Less than 24-hour service (39%)	Less than 24-hour service (59%)	
	Unfair distribution (31%)	Poor water quality (19%)	
	Poor water quality (21%)	Unfair distribution (16%)	

Most respondents (78%) said that their choice of tariff structure was based on what they thought would be best for everyone in Kathmandu, not just themselves; 22% said that they were thinking about their own household. Those who preferred the IBT were more likely to report that they based their decision on what was good for everyone in Kathmandu (84%) compared to those who preferred the uniform tariff (70% said they based their decision on what was good for everyone in Kathmandu).

We then asked the reasons for preferring one tariff structure over the other. Those who chose the IBT said that they like the fact that they could ‘get [a] discount if [they] use less water’

(42%), suggesting that the price of water in the higher-priced blocks may have been perceived as the default price. They also believe that 'people who consume more water should pay [a] higher price for the extra water they consume' (30%). Those who chose the uniform tariff said that they liked the fact that it is the 'same price for all customers' (42%), that it '[encourages] water conservation' (21%), and that because 'the cost of supplying water is the same, the price should also be the same' (20%).

For those who answered that they were thinking mostly about their own family, we asked if their tariff structure preference would change if they thought about all households instead of just about themselves. Twenty-three per cent of those who initially chose the IBT stated they would change their answer. Similarly, 21% of those who initially chose the uniform tariff also said that they would change their answer. In contrast, only about 2% of those who said they based their decision on what was good for everyone in Kathmandu stated they would change their answer if they were thinking only about their own family.

Finally, we asked respondents if those with a connection to the piped water network should be able to choose the tariff plan that they want, just as cell phone users are. A majority of respondents (68%) responded yes, households should be able to choose, while 18% said households should not be allowed to, and 14% of respondents were unsure.

Table 6 presents the summary statistics for the dependent variables used in Equations (1)–(3), the key socioeconomic characteristics of the household (income, household size, respondent's education, head of the household responding), variables related to water usage (monthly expenditures, quantity of water collected from the tap), water shortage being the most important environmental problem, and other independent variables of interest. The literature on determinants of household preferences for IBTs is limited and provides little guidance on appropriate model specifications and covariates. Crase et al. (2007) find that households that supported an IBT are more likely to report a larger number of activities that use water. They also include socioeconomic variables as co-variates but find no significant association between household support for an IBT and age, household size, household income, or the size of the last water bill.

Table 4.6. Summary statistics

Variable	Variable description	N	Mean	SD	Min	Max
ibt	Increasing block is best for KUKL to adopt (1 = yes, 0 = no)	1,210	0.58	0.49	0	1
fixed	Favors fixed charge in water bill (1 = yes, 0 = no)	1,439	0.40	0.49	0	1
fair_bill	Fair water bill post-Melamchi (NPR/month)	1,283	528	637	100	10,000
hyp_usage	Exogenously assigned hypothetical household usage (L)	1,500	16,150	8,118	5,000	30,000
hyp_usage_sq	Hypothetical household usage squared	1,500	3.3×10^8	2.8×10^8	2.5×10^7	9.0×10^8
ln_income	ln(Total household reported income)	1,450	10.92	0.76	6.21	13.92
nhh	Household size	1,500	5.05	2.12	1	15
resp_edu	Years of education of respondent, with missing values coded as zero	1,500	8.38	6.22	0	18
resp_edu_missing	Education is missing (1 = yes, 0 = no)	1,500	0.219	0.413	0	1
resp_hhhead	Respondent is household head (1 = yes, 0 = no)	1,500	0.529	0.499	0	1
ln_monthlywaterexp	ln(Perceived monthly expenditures on water (NPR))	1,500	725	921	0	9,130
pwc_m3	Estimated quantity of water collected from piped water connection (m^3/month, dry season)	1,500	2.49	4.81	0	90
priority_water	Water shortage is first most important environmental problem (1 = yes, 0 = no)	1,500	0.57	0.50	0	1
consider_ktm	When choosing preferred tariff, thinking about what is best for everyone in Kathmandu (1 = yes, 0 = no)	1,500	0.76	0.42	0	1
change_mind	Answer would change if thinking about other group (either own hh or everyone) (1 = yes, 0 = no)	1,500	0.07	0.25	0	1

Table 4.7. Stated preferences for IBTs and fixed charges

	No fixed charge	Fixed charge	Total
Uniform	201	297	498
IBT	494	175	669
Total	695	472	1,167

Table 7 shows the relationship between the stated preferences for an IBT and a fixed charge. Forty-two per cent of the sample (N = 1,167) prefer an IBT but not a fixed charge; 25% prefer a fixed charge and a uniform tariff instead of an IBT. Seventeen per cent do not want a fixed charge and do not prefer an IBT; 15% prefer both a fixed charge and an IBT. The tetrachoric correlation coefficient is estimated at −0.509, with an asymptotic standard error of 0.038, showing that those who prefer an IBT are less likely to prefer a fixed charge.

Table 8 reports the results of the bivariate probit model of preferences for IBTs and fixed charges. The first specification for both models looks only at socioeconomic controls: income, household size, respondent education, and if the respondent is the head of the household. Models (1) and (2) are estimated simultaneously. Model (1) shows that for household preferences for IBTs, income and household size do not have significant coefficients. More educated respondents are more likely to choose an IBT, and respondents that are household heads are less likely to choose an IBT. There are also municipality effects; households living in Kirtipur and Madyapur Thimi are more likely to choose an IBT compared to households living in Kathmandu (municipality). Model (2) shows that for household preferences for fixed charges, household income, and head of household have statistically significant coefficients at the 1% and 10% levels, respectively. The higher the household income, the less likely the household is to prefer a fixed charge. Heads of households are more likely to prefer a fixed charge. Household preferences for fixed charges do not have a statistically significant relationship with household size, respondent education, or municipality.

The second set of specifications in Table 8 adds covariates related to water usage: monthly water expenditures (ln_monthlywaterexp), quantity of water collected from the private tap (pwc_m3), and if water shortage is the most important environmental problem (priority_water). Models (3) and (4) are estimated simultaneously. In model (3), the coefficient on quantity of water collected from the private tap (pwc_m3) is significant at the 1% level and is negative. The more water the respondent's household obtains from the private water connection, the less likely they were to choose an IBT. The addition of these water usage variables does not change the sign or significance of other variables, except for size of household (nhh), which becomes significant at the 10% level. In model (4), the coefficients on the water usage variables are not statistically significant.

The third set of specifications includes two additional variables: (1) whether the respondent was thinking about her own household or all of Kathmandu (consider_ktm) and (2) if they would change their mind (change_mind) when considering the other group instead (either own household or all of Kathmandu). Models (5) and (6) are estimated simultaneously. In model (5), the coefficient on whether the respondent considers all of Kathmandu when selecting the preferred tariff structure (consider_ktm) is positive and significant at the 1% level. When the respondent considers the larger community, they are more likely to select an IBT over a uniform volumetric tariff. In model (6), we find that neither considering all of Kathmandu nor changing their mind have statistically significant effects on household preferences for a fixed charge.

Table 4.8 Biprobit regressions of preferences for IBTs and fixed charges

Variables	(1) ibt	(2) fixed	(3) ibt	(4) fixed	(5) ibt	(6) fixed
ln_income	0.0710	−0.158***	0.0800	−0.156**	0.0859	−0.156***
	(0.0582)	(0.0583)	(0.0589)	(0.0620)	(0.0575)	(0.0604)
nhh	−0.0327	0.0139	−0.0365*	0.0155	−0.0395*	0.0178
	(0.0213)	(0.0176)	(0.0210)	(0.0174)	(0.0224)	(0.0174)
resp_edu	0.0227***	0.00384	0.0237***	0.00371	0.0221***	0.00407
	(0.00723)	(0.00966)	(0.00693)	(0.0100)	(0.00719)	(0.0100)
resp_edu_missing	0.252**	−0.00805	0.263**	−0.0148	0.234*	−0.00697
	(0.119)	(0.127)	(0.115)	(0.126)	(0.121)	(0.126)
resp_hhhead	−0.175**	0.159*	−0.189**	0.166**	−0.204**	0.176**
	(0.0744)	(0.0861)	(0.0776)	(0.0845)	(0.0797)	(0.0860)
ln_monthlywaterexp			0.0394	−0.0329	0.0480	−0.0360
			(0.0340)	(0.0228)	(0.0331)	(0.0224)
pwc_m3			−0.0445***	0.00811	−0.0498***	0.00984
			(0.0136)	(0.0108)	(0.0134)	(0.0113)
priority_water			−0.0693	−0.0901	−0.0378	−0.105
			(0.102)	(0.110)	(0.0983)	(0.109)
consider_ktm					0.590***	−0.243
					(0.142)	(0.175)
change_mind					0.203	0.136
					(0.160)	(0.207)
Municipality – Lalitpur	0.270*	−0.0353	0.254	−0.0490	0.205	−0.0173
	(0.158)	(0.150)	(0.165)	(0.146)	(0.160)	(0.155)
Municipality – Bhaktapur	0.210	0.183	0.318	0.105	0.277	0.101
	(0.160)	(0.136)	(0.225)	(0.141)	(0.243)	(0.137)
Municipality – Kirtipur	0.768***	−0.139	0.895***	−0.251	0.886***	−0.222
	(0.137)	(0.165)	(0.195)	(0.167)	(0.199)	(0.171)
Municipality – Madhyapur Thimi	0.629***	0.0934	0.613***	0.111	0.588***	0.147
	(0.205)	(0.162)	(0.211)	(0.176)	(0.217)	(0.180)
Constant	-0.724	1.292**	-0.895	1.480**	−1.423**	1.654***
	(0.640)	(0.600)	(0.665)	(0.648)	(0.631)	(0.641)
Observations	1,135		1,135		1,135	
Rho	−0.518***		−0.514***		−0.506***	
Wald test of rho = 0 (p-value)	0.000		0.000		0.000	
AIC	2,916		2,905		2,873	
Wald Chi-square	170.1		225.7		403.8	
Correct classification (%)	43.6%		45.2%		45.3%	

Robust standard errors in parentheses.
*** p < 0.01, ** p < 0.05, * p < 0.1.

Across all specifications, the value of the correlation between the error terms of the IBT and fixed charge equations (rho) and its significance level are reported. All specifications show rho values that are significant at the 1% level, rejecting the null hypothesis that rho = 0 and that the error terms are uncorrelated. Comparing the specifications, we look at the Akaike information criteria (AIC). The last specification reports the lowest AIC of 2,873 and is therefore the preferred specification. The Wald Chi-square test statistics are sufficiently high for all models to reject the null hypothesis that all coefficients in the model are zero. However, the ability for the three specifications to correctly classify both outcomes is low, ranging from 43.6% to 45.3%.

The models describing household preferences for IBTs and fixed charges are relatively weak, with low predictive abilities. However, we do find that households that are more likely to be large users (larger household and higher monthly water consumption) are less likely to favor IBTs. This is not surprising if households are rational economic actors and are cost-minimizing. Additionally, considering what is good for Kathmandu as a whole has a large and significant coefficient, suggesting that households' intuition and opinions agree with common pro-IBT arguments (Boland & Whittington, 2000). Paired with the qualitative questions about reasons for preferring one tariff structure over another, these findings make sense. It would seem that ideas about fairness or social justice (i.e., 'good for everyone in Kathmandu'), cost-minimization, and water conservation drive household preferences, and are not easily approximated using household socioeconomic and water use characteristics.

4.6.3 Preferences for Nonlinear Tariff Structures: Fair Water Bills

Figure 1 presents the frequency distributions of respondents' reported fair water bills at each of the exogenously assigned monthly quantities of water use. These frequency distributions show that reported fair water bills gradually shift higher as the quantity of water increases, but many respondents reported very low 'fair water bills' at all quantities. There was also a great deal of heterogeneity in reported fair water bills at each exogenously assigned monthly quantity of water use.

Figure 4.1. Distribution of responses for fair monthly water bill by exogenously assigned hypothetical household usage

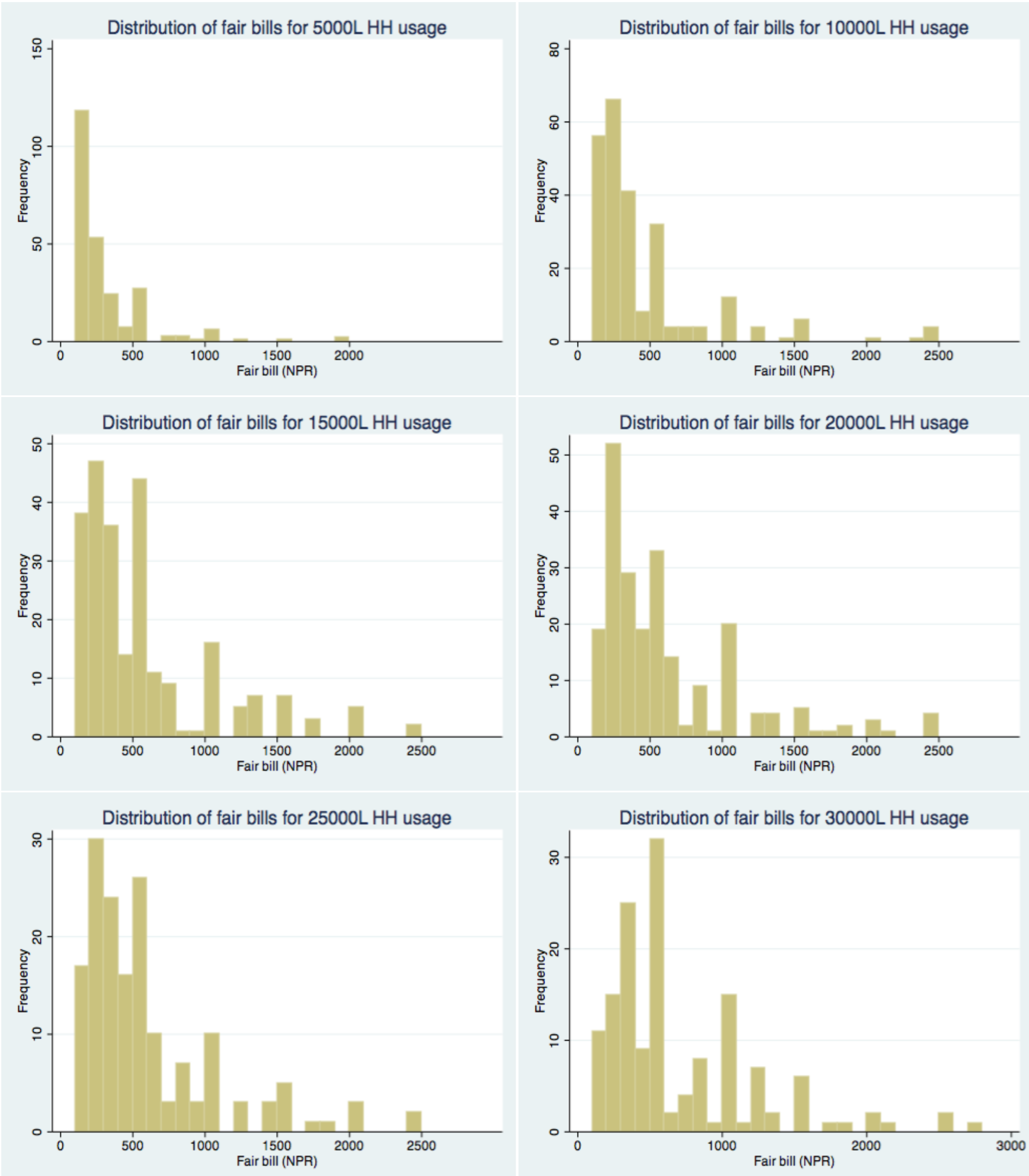


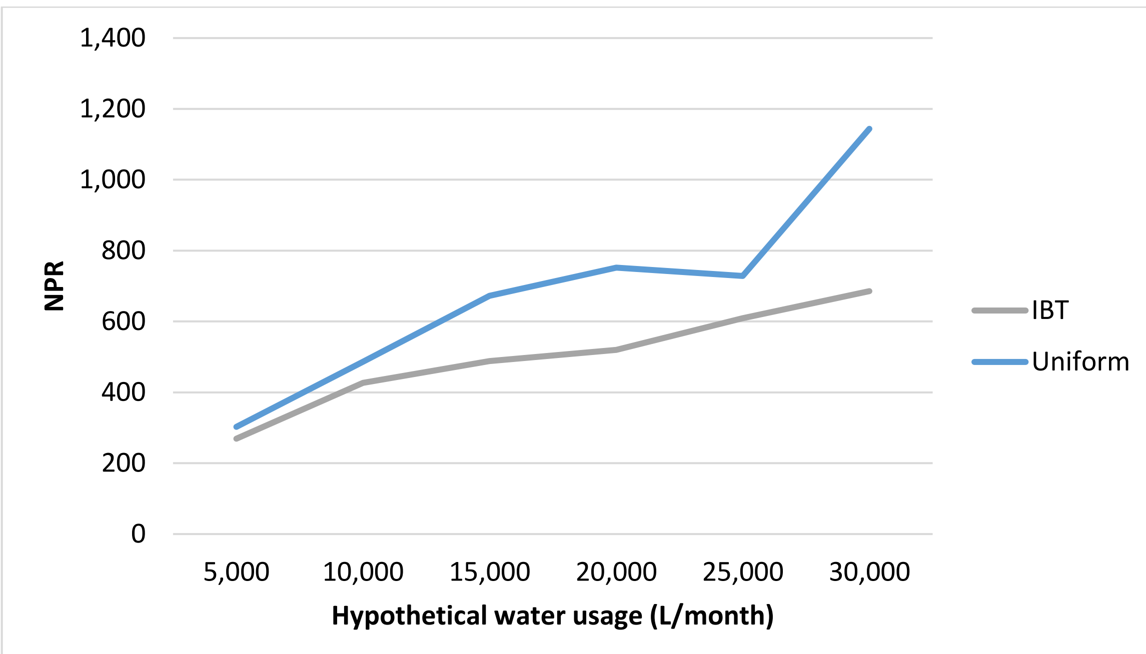
Table 9 describes respondents' reported fair water bills and implicit average water prices at different hypothetical monthly quantities of water, with references to what the water bill and average water price would be under the current KUKL water tariff structure. For the overall sample, the fair water bill is monotonically increasing as a function of hypothetical water use. The mean fair water bill is higher than what the household would pay under the current tariff for all hypothetical water use levels. The correlation coefficient between fair water bill and the hypothetical monthly water quantity is positive but low (Pearson's is 0.27 and Spearman's is 0.38). Many respondents report a very low 'fair water bill' at all quantities. The implicit average water price is monotonically decreasing in volume of water use (except for the mean price at 30 m^3/month). Again, the mean implicit average water price is also much higher than what the household would pay under the current tariff – more than double for 5, 10, and 15 m^3.

Table 4.9 Fair water bill by hypothetical use

Hypothetical water use (m^3/month)			Fair water bill (NPR/month)			Implicit average water price (USD/m^3)			
	N	Current tariff	Median	Mean	SD	Current tariff	Median	Mean	SD
5	246	100	200	272	270	0.21	0.41	0.56	0.56
10	244	100	288	423	438	0.11	0.30	0.44	0.45
15	247	260	400	546	542	0.18	0.27	0.38	0.37
20	224	420	400	580	518	0.22	0.21	0.30	0.27
25	168	580	450	680	979	0.24	0.19	0.28	0.40
30	154	740	500	835	909	0.26	0.17	0.29	0.31
Prefer increasing block tariff									
5	120	100	200	269	287	0.21	0.41	0.55	0.59
10	115	100	300	427	432	0.11	0.31	0.44	0.45
15	114	260	325	489	382	0.18	0.22	0.34	0.26
20	105	420	400	520	433	0.22	0.21	0.27	0.22
25	81	580	400	610	779	0.24	0.16	0.25	0.32
30	65	740	500	686	862	0.26	0.17	0.24	0.30
Prefer uniform volumetric tariff									
5	88	100	200	303	282	0.21	0.41	0.62	0.58
10	84	100	300	486	513	0.11	0.31	0.50	0.53
15	86	260	500	673	600	0.18	0.34	0.46	0.41
20	76	420	500	752	669	0.22	0.26	0.39	0.34
25	51	580	500	728	629	0.24	0.21	0.30	0.26
30	49	740	1000	1144	891	0.26	0.34	0.39	0.31

Comparing the frequency distributions of reported fair water bills for those who preferred an IBT with those who prefer a uniform volumetric tariff, we see lower fair water bills and implicit average water prices reported at each hypothetical water use level for respondents who preferred an IBT (Table 9 and Figure 2). However, the mean implicit average prices are still mostly higher than that under the current tariff. The fair water bill stated by those who prefer the uniform volumetric tariff for the largest quantity (30 m^3/month) is nearly double that of the fair water bill stated by those who prefer an IBT (median of 500 NPR vs 1,000 NPR).

Figure 4.2. Fair water bill (NPR)



The implicit average water price for households that stated they preferred an IBT decreases as a function of hypothetical water use at the aggregate level. This reflects an inconsistency between the household and aggregated levels. While individual households may state that they support increasing average water prices as a function of water use, when these households' responses are aggregated, the opposite is true – average water prices decrease as a function of water use. The results in Table 9 show that households that express a preference for IBTs, in aggregate, report a ‘fair water bill’ that implies the implicit price should decrease as volume increases (which is not consistent with an IBT structure).

Table 10 reports the regression results for Equation (3), with four different model specifications. As expected, β_1 is positive and robustly statistically significant across all specifications, confirming that respondents perceive that it is fair for households who use more water to pay more in total. However, β_2 is negative but not statistically significant, suggesting that respondents do not prefer increasing non-linear tariff structures such as IBTs. The last model specification includes preferences for IBTs and the interaction between ibt and hyp_usage_sq. The coefficient on ibt is not statistically significant, but the coefficient on the interaction term is. This implies that a preference for IBTs modifies β_2 negatively, which is the opposite of what we would expect. For those who believe households that use more water should pay increasingly higher water bills, β_2 should be positive. Household income is positively associated with higher reported fair water bills, as are higher monthly water expenditures. The R^2 values for the model specifications range from 0.12 to 0.18.[13]

[13]Appendix Table B.3 presents results for the same set of specifications, but separately for those who prefer an IBT and for those who prefer a uniform volumetric tariff. We find that the relationship between quantity and price (β_1) holds for those who prefer a uniform volumetric tariff, but find no significant relationship (β_1 and β_2) for those who prefer an IBT. Our results are not sensitive to the exclusion of respondents who did not pass the check question on understanding of the IBT concept. Appendix Table B.4 presents the results for the entire sample. The sign and significance of key coefficients β_1 and β_2 remain robust. The magnitude of β_1 remains stable at 0.02 across all specifications. Appendix Table B.5 modifies the model by including a dummy variable for the initial failure of the check question (check_understanding). While the coefficient on the response to the check question is statistically significant, the sign and significance of β_1 and β_2 remain the same.

Table 4.10 Regressions of fair bill on hypothetical monthly usage

Variables	(1) fair_bill	(2) fair_bill	(3) fair_bill	(4) fair_bill
hyp_usage	0.0256**	0.0225**	0.0238**	0.0242**
	(0.0105)	(0.0106)	(0.0109)	(0.0108)
hyp_usage_sq	-1.44×10^{-7}	-6.45×10^{-8}	-1.04×10^{-7}	7.93×10^{-8}
	(3.33×10^{-7})	(3.37×10^{-7})	(3.50×10^{-7})	(3.19×10^{-7})
ln_income		121.0***	101.0***	106.5***
		(38.71)	(36.27)	(35.57)
nhh		−6.776	−9.864	−12.51
		(9.062)	(9.389)	(9.036)
resp_edu		1.547	1.088	1.935
		(4.296)	(4.235)	(4.468)
resp_edu_missing		31.25	35.81	47.61
		(52.18)	(53.39)	(53.62)
resp_hhhead		97.02***	86.27***	73.97**
		(31.74)	(30.93)	(30.21)
ln_monthlywaterexp			32.21***	35.00***
			(10.71)	(9.053)
pwc_m3			6.425	3.045
			(4.389)	(3.761)
priority_water			−57.20	−57.43
			(35.86)	(34.45)
ibt				−55.45
				(55.15)
ibtXhyp_usage_sq				-3.21×10^{-7}*
				(1.68×10^{-7})
Municipality – Lalitpur	−112.3	−86.07	−66.31	−49.13
	(67.76)	(65.44)	(64.42)	(58.90)
Municipality – Bhaktapur	−288.1***	−215.1***	−121.2	−96.27
	(62.37)	(67.57)	(98.56)	(93.22)
Municipality – Kirtipur	−346.9***	−296.8***	−213.1***	−161.8***
	(58.04)	(50.92)	(58.88)	(46.51)
Municipality – Madhyapur Thimi	−154.1**	−91.77	−88.40	−53.98
	(75.91)	(76.43)	(76.41)	(69.96)
Constant	251.9***	−1,102***	−1,041***	−1,079***
	(73.83)	(372.8)	(362.4)	(349.4)
Observations	1,040	1,011	1,011	1,005
R^2	0.116	0.140	0.157	0.177
F-statistic	18.17	12.81	12.00	13.28
Prob > F	0.000	0.000	0.000	0.000

Clustered standard errors in parentheses.
*** p < 0.01, ** p < 0.05, * p < 0.1.

Our analysis suggests that respondents do not have strong preferences for IBTs or other increasing nonlinear tariff structures. Even though a small majority of respondents (58%) said that they prefer IBTs to uniform volumetric prices in response to a direct question, after controlling for household characteristics and neighborhood unobservables, we find little evidence that households prefer increasing nonlinear tariffs. We believe that many respondents simply wanted cheap, affordable piped water services, and that water bills should be calculated fairly for everyone in Kathmandu, which they do not necessarily associate with an IBT or other increasing nonlinear tariff structure.

Water shortage was clearly a salient problem, with strong, explicitly stated dissatisfaction regarding the level of service and the fairness of distribution. Increases in household water use would occur in bathing, cleaning, and gardening. Household preferences also reflect a strong desire for more affordable water. Households are currently receiving little water from their taps and paying an average of US\$1.75/m^3 (SD 3.47). Implicit average water prices from stated fair bills are significantly lower (see Table 9).

We found that preferences for tariff structure are difficult to associate with socioeconomic variables. Instead, it seems that preferences are driven by desires for cost-minimization and fairness. When it comes to IBTs, the variable with the strongest explanatory power is consideration of what is best for other households. It also seems that households who use less water understand that they will pay less under an IBT. Overall fairness is a large concern, but the interpretation of fairness varies. Those who prefer an IBT believe that people who use less can get a discount and those who consume more should pay higher prices for the extra water they consume. Those who prefer a uniform tariff believe that all customers should pay the same price.

From Figure 2 and Tables 9 and 10, there is evidence for a positive relationship between price and quantity of water. Fair water bills generally increase monotonically as a function of water use. However, subsample analysis (see Appendix Table B.3) shows that the significant relationship between quantity and price is driven by those who prefer a uniform volumetric tariff. For those who prefer an IBT, neither β_1 nor β_2 are significant. While there is an overall positive relationship between water use and water price, there is little evidence in support of IBTs.

4.7 Conclusions

We find that households are primarily concerned with the perceived fairness of the water tariff structure. Based on their responses about 'fair water bills' for exogenously assigned quantities, households appear to support a water tariff that is a function of the quantity of water used. Importantly, the notion of fairness varies across the population. For those who prefer an IBT, fairness means that people who use less should get a greater discount per unit of water used than those who consume more. In contrast with this position, fairness among those who prefer a uniform tariff means that all customers should pay the same price regardless of the quantity of water they use.

Perhaps surprisingly, there is little evidence that households prefer that water tariffs be structured in a way that ensures poor households have access to sufficient quantities of water at affordable prices. While this is an important objective of consultants, water utility managers, and international donors, our sample households seem more concerned about the price level generally instead of the affordability of piped water services for poor households.

Our multivariate analysis illustrates how household preference for tariff structure can be analyzed and results interpreted. The simple descriptive statistics show that a small majority of respondents (58%) said that they prefer IBTs to uniform volumetric prices in response to a direct question, might lead to a 'naive' conclusion that IBTs are preferred by the most households. But after controlling for household characteristics and neighborhood unobservables, we find little evidence that households have strong preferences for increasing nonlinear tariffs.

Our findings have important implications for the choices over different water tariff structures. One reason IBTs are popular with water utility managers may be that they believe citizens consider IBTs to be fair. Water utility managers may be unaware that their customers may have alternative notions of fairness, and that many may not, in fact, favor IBTs. In most cities in low- and middle-income countries, the volumetric prices in all the blocks of an IBT are below the average costs of service. Our findings are consistent with the hypothesis that this may be due in part to the fact that there may be little customer support for high volumetric prices in the upper blocks.

Water utility managers should take household preferences into account when choosing a tariff structure. However, because household preferences for water tariff structures in Kathmandu are heterogeneous, utility managers may have considerable latitude in choosing a tariff structure that best achieves the utility's objectives of cost recovery and revenue stability. As long as the utility managers focus on and communicate the affordability and fairness of the water tariff, they should be able to garner public support for tariff reforms.

Finally, we suggest that there is a need for further empirical research on households' notions of fair ness and social justice and how households assess the consequences of changes in both tariff structures and price levels in terms of these criteria. Additionally, as this study did not examine household preferences about sizes and prices of blocks in an IBT, future work is needed to more clearly understand both individual and aggregate preferences about more detailed features of IBTs.

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CHAPTER 5: THE STRUCTURE OF WATER VENDING MARKETS IN KATHMANDU, NEPAL[14]

5.1 Introduction

Despite decades of effort by governments and donor agencies to expand piped water connections, water vending continues to play a major role in water supply for urban residents in many parts of Africa (Whittington et al., 1991; Collignon & Vézina, 2000; Zuin et al., 2014), South America (Casey et al., 2006; Wutich et al., 2016), and Asia (Crane, 1994; Conan & Paniagua, 2003). Because of the unreliability and poor service of piped water systems in many countries, even households connected to a piped network often rely heavily upon private vendors as a major source of water supply (Keener et al., 2009; Ahlers et al., 2013). In fact, inviting water vendors into public–private partnerships in the urban water supply and sanitation sector has emerged as a policy option (Opryszko et al., 2009).

While there is no doubt that water vending has greatly improved access to potable water for millions of people, especially the poor, in developing countries, the social, economic, and environmental consequences of reliance on informal water markets need careful examination. Water supplied by informal water markets may pose serious human health risks (Zaroff & Okun, 1984; Kjellén & McGranahan, 2006; Appiah Obeng et al., 2010) and undermine policies to improve social equity (Wutich et al., 2016).

It is often assumed that the presence of many private water vendors, coupled with relatively few entry barriers, would keep such markets competitive (Ahlers et al., 2013). Yet, the high prices

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charged by private water vendors, ranging from 400 to 100 times the amounts charged under municipal water tariffs (Zaroff & Okun, 1984; Bhatia & Falkenmark, 1993; Crane, 1994; Snell, 1998; Solo, 1999), raise concerns about the presence of 'monopoly rent' in such markets (Whittington et al., 1991). The competitiveness of informal water markets may also be undermined by collusion among providers and by price fixing by water vendors' business associations (Whittington et al., 1991; Crane, 1994; Snell, 1998; Collignon & Vézina, 2000; Ahlers et al., 2013).

There has been limited empirical research on the structure and competitiveness of informal water markets (Ahlers et al., 2013). Researchers face several methodological challenges. First, record keeping and reporting among vendors operating in informal markets are generally poor. Second, it is often difficult to collect business information from water vendors regarding their operations, especially data regarding financial particulars such as sales, costs, and profits, as vendors may guard such information as proprietary. Third, systematic sampling is rare, due to a lack of knowledge about the appropriate sampling frame for informal markets, and, as a result, the representativeness of findings is often in question. Most of the existing empirical work has been based on surveys of tanker truck operators and of distributing vendors (e.g., individuals selling water door-to-door in pushcarts) and rarely includes surveys of owners of private water vending businesses.

Kathmandu, Nepal was chosen for a case study because its booming water vending industry arose from two conditions common to many cities: a municipal utility that fails to deliver adequate water to its population over a significant period of time and a rapidly growing population that is partly dependent on alternative sources of water. As we document below, because private water sales comprise a significant proportion of the water supplied to end users in Kathmandu, the city provides an opportunity for in-depth research into the structure of a large urban water market. Many cities in the developing world exhibit similar features and issues. Lessons learned from the analysis presented here may assist policymakers in other cities in developing countries.

Drawing upon data collected in 2014 from in-person interviews with 120 water vendors and from respondents in 1,500 households, as well as from key informant interviews, this analysis presents an in-depth portrait of the structure of the informal water market in Kathmandu. We document the presence of five main types of water vending (commercial water source abstraction, tanker truck delivery, bottled water production, household delivery by distributing vendors, and sale of both bulk and bottled water by retail outlets such as neighborhood kiosks and private shops) and show that these functions may be consolidated in various ways. Financial analysis of the revenues and costs of commercial water source vendors and tanker truck vendors reveals that these businesses do not appear to be earning monopoly rents. That is, these components of the water vending supply chain appear reasonably competitive.

5.2 Background and Study Area

Although Nepal is one of the least urbanized countries in the world (only 17% of its population lives in urban areas), it is urbanizing rapidly. The urban population has increased 6% annually since the 1970s. This growth has occurred within a context of political instability. The first local elections in more than two decades were held in May 2017. During the lengthy preceding interval, Kathmandu, the nation's capital city had not had an elected local government but was run by officials of the central national government. That government was unable to cope with extreme unplanned urban development that had been exacerbated by an influx of migrants from rural areas, due in part to the decade-long Maoist insurgency (1996–2006). Kathmandu became a sprawling urban metropolis, with high levels of pollution, inadequate water and sanitation systems, increasing traffic congestion, and a growing energy crisis.

The Kathmandu Valley lies upstream of the Bagmati River Basin, which is regarded as one of the most water-stressed basins in the country (Pandey et al., 2010a, 2010b). Groundwater has long been and continues to be an important source of water supply in the area. Significant groundwater abstraction started in the mid-1980s, when the Nepal Water Supply Corporation (NWSC) introduced groundwater into the municipal water supply system, and it became the most reliable source of water for the increasing urban population (Pandey et al., 2009). Since 1986, the abstraction rate has exceeded the recharge rate, which has resulted in falling groundwater levels.

The municipal water supply system in Kathmandu is comprised of four distinct components:

1. the traditional water system, consisting of stone spouts, dug wells, tanks, and ponds that were built over several centuries;
2. the piped network system;
3. private water extraction by households and industries; and
4. various types of water vending.

The traditional stone spout system is a unique aspect of the water supply system in the valley. Historically, the spouts were connected to a network of canals that delivered water from upland sources to storage ponds. These ponds, in turn, recharged shallow groundwater aquifers that maintained a flow to the stone spouts or dug wells. A study conducted in 2007 revealed that of the 400 original stone spouts in the valley, only about half were still functional (UN-HABITAT, 2007).

The first piped water distribution network was introduced in 1891. At the time, its main purpose was to serve the families of the rulers and elites in Kathmandu. In 1928, the system was expanded to supply the general public. In 1972, the World Bank made a loan to the Nepalese Government to improve urban water supply and wastewater services. The Water Supply and Sewerage Board, formed in 1974, was renamed the Nepal Water Supply Corporation (NWSC) in 1989. In 2006, the Kathmandu Valley Water Supply Management Board Act was passed, which divided the NWSC into three separate organizations. Since then, the Kathmandu Upatyaka Khanepani Limited (KUKL) has been designated as the sole service operator and responsible for providing water and sewerage services to the people of the entire valley.

Between 2001 and 2011, the population of Kathmandu increased from 1.1 to 1.7 million (CBS, 2012), but very little corresponding investment has been made in the piped water system, which led to a substantial gap between the supply and demand. In 2014, water demand in the valley was estimated to be 360 million liters per day (MLD). The public water utility's current production reaches only about 76 MLD in the dry season and 123 MLD in the wet season (KUKL, 2014). In addition, annual losses from the municipal piped water supply system have been estimated to be over 70% (Dixit & Upadhya, 2005).

The result of this state of affairs is that as of 2014, less than 20% of the population was receiving a reliable supply of piped drinking water (ADB, 2010). To overcome the shortages, a long-term investment program is in progress to divert water from the Melamchi River outside the valley and deliver it to Kathmandu via a long (26 km) tunnel (Dixit & Upadhya, 2005). This project has experienced protracted delays. The current gap between demand and supply in Kathmandu is being met primarily through private groundwater extraction by households and vendors and through sales of water from a variety of private water vendors.

5.3 Research Design and Fieldwork

For our research in Kathmandu Valley, we used a mixed-methods research approach that incorporated data from structured household and vendor surveys as well as from in-depth key informant interviews. This combined strategy made it possible to triangulate our findings from multiple sources and extrapolate these findings to the city as a whole. A mixed-methods approach seemed especially appropriate because only limited and dispersed knowledge was available about the various unregulated water vendors. All data collection activities were conducted in Kathmandu in 2014.

Adopting protocols for data collection from a similar study (Whittington et al., 1989), we conducted a survey of 120 water vendors engaged in various combinations of three activities along the water vending supply chain: (1) commercial abstraction of bulk water from natural sources or bore holes (i.e., not from the piped system), (2) tanker truck delivery of bulk water to end users, and (3) bottled water production. In our sample, "vendors with commercial water sources" thus refer to vending businesses that owned water sources and sold bulk water in large or small quantities from supplies other than the piped water system. Our descriptor "vendors with tanker trucks" refers to businesses that used tanker trucks to deliver bulk water to households and businesses. Our third category, "vendors with bottled water facilities," are operations that produce bottled water, that is, treated drinking water packaged in 20-L plastic "jars" or 1-L bottles. For purposes of analysis, "integrated vendors" involved in more than one of these operations were assigned compound names.

Figure 5.1. Map of Kathmandu Valley, showing the location of vendors interviewed

For the water vendor survey, lists of commercial water source vendors, tanker truck vendors, and bottled water vendors were collected from the central offices of the vendors' respective business associations: the Valley Drinking Water Source and Tanker Entrepreneurs

Association (VDWTEA) and the Nepal Bottled Water Industries Association (NBWIA). The commercial water source list was verified by field visits and consultations with the owners of different boreholes and raw water sources, such as springs.[15] From in-depth interviews with KUKL and the heads of the business associations, we determined that the associations' membership lists were the best sampling frame for the water business population, representing the majority of vendors operating in the Kathmandu Valley. According to these two lists, there are approximately 67 commercial sources of water, 700 tanker trucks supplying the city with water through 210 vendors, and 200 bottled water vendors selling drinking water through 20-L jars and 1-L bottles. From the lists, we drew three random samples: (1) 40 from the list of commercial water source vendors; (2) 40 from the list of vendors with tanker trucks; and (3) 40 from the list of bottled water vendors. Figure 1 shows the location of the vendors we interviewed.

For all three types of vendors, we specifically wanted responses from the business owners. If an owner was unavailable, we instead solicited responses from the manager. Overall, of the 120 vendors we surveyed, 84% of the respondents were owners. Of the vendors with a commercial water source (along with any level of integration with other water business activities), 82% were owners. All of the vendors with only tanker trucks had owners as respondents. For vendors with only bottled water facilities, 70% of respondents were owners.

The water vending survey instrument presented questions that were common for all types of vendors, such as growth of their operations, customer numbers and types, relationship with the association (if a member), service details, operational and capital costs, and major challenges faced. The survey instrument also included three separate sections containing questions specific to the

[15] This list only included commercial water source vendors who sold to independent tanker truck vendors and did not have their own tanker trucks. Vendors with commercial water sources who had their own tanker trucks were included on the tanker truck association list. Some tanker truck vendors had their own sources as well, but they were not categorized as 'commercial water source vendors' if they only supplied water to their own tanker trucks.

type of water vending (e.g., whether the vendor produced bulk water at a commercial water source, delivered bulk water with tanker trucks, and/or produced bottled water). The survey instrument was designed to allow for varying kinds and levels of consolidation among these three activities. We did not examine the distribution of bottled water or the sale of bulk water at retail outlets.

We also conducted a large household survey (*n* = 1,500), which included questions about the quantities of water a household purchased from different types of vendors and the prices paid (Gurung et al., 2017). In addition, nine in-depth key informant interviews were conducted with government officials from KUKL and Kathmandu Valley Water Supply Management (KVWSM), the most recently elected mayor of Kathmandu, a retired university scholar, development practitioners, and the presidents of the two business associations (VDWTEA and NBWIA).[16]

The household survey covered respondents from 1,500 households across the five municipalities of Kathmandu Valley—Kathmandu itself, and Lalitpur, Madhyapur, Kirtipur, and Bhaktapur. These sample households had been previously surveyed in 2001 (Pattanayak et al., 2005). In 2001 these household clusters were located using aerial maps provided by the Central Bureau of Statistics for the 1996/1997 World Bank Living Standard Measurement Survey for Kathmandu. In three of the five municipalities in the Kathmandu Valley (Kathmandu, Lalitpur, and Bhaktapur), a previously conducted complete enumeration of all households was used as the sample frame (SILT Consultants and Development Research and Training Center, 1999). For Kirtipur and Madhayapur, the 1991 population census was used as the sampling frame. Wards were then selected from the sampling frame on the basis of a probability-proportional-to-size sampling approach that ensured households had an equal opportunity of being included in the sample (Babbie, 1990). After a ward was selected for inclusion in the sample, sub-wards were drawn randomly. The final sample consisted of 60 clusters of 25 households each, covering all five

[16] Approval for the two surveys and for the informant questionnaire, and for their implementation protocols, was obtained from the National University of Singapore's Institutional Review Board.

municipalities in the Kathmandu Valley. In each cluster selected for inclusion in the sample, respondents from all 25 households were interviewed for the study. Because probability-proportional-to-size sampling depends on the size of population, some wards had more than one cluster in the final sample.

For the 2014 survey, if a household included in the 2001 survey could not be located, a nearby household in the same cluster was selected as a replacement. When a household head from the 2001 survey was unavailable, the present head or another responsible member of the household was chosen instead. In total, we were able to locate and re-interview a respondent in 927 of the 1,500 households visited in 2001. Thus, the 2014 survey included 573 replacement households.

The nine key informant interviews were audio-recorded with prior written permission obtained from the interviewees. In addition, written notes were taken during the interviews. Government officials and scholars were asked about the major milestones in the history of water infrastructure investment in Kathmandu Valley, major challenges faced in the development of urban water and sanitation services, institutional roles and responsibilities, and the growth of the private water market. We also discussed with key informants their interactions with the private water vendor market,[17] access of vulnerable and poor populations to water and sanitation services, and impediments to expanding the piped network to all residents. Chairpersons of the two vendor associations were asked questions regarding the history and organizational structure of their respective organizations, their relationship and interaction with the government, and their main activities, including lobbying, as well as the factors that influenced whether water vendors joined their association.

[17] For example, the public water utility had its own tanker trucks for distributing bulk water, thus competing with the private water tanker vendors. KVWSM decided key regulations, such as permits for commercial water sources. Ultimately, the associations were formed, organizing the various types of water vendors.

The information obtained from the household and water vendor surveys was used to estimate the city-wide scale of quantities of water sold and of money paid and received at different points in the water vending supply chain. These estimates were cross-checked against information we had received from the informant interviews. In addition, we estimated the total water supplied by the public water distribution network, using water use data from our household survey and estimates of the total number of connections in the city (≈195,000).

Detailed financial data were collected from commercial water source vendors and the tanker truck vendors. These data enabled us to construct monthly accounts of revenues and costs using standard financial accounting methods. By constructing a basic financial statement for each vendor, we were able to assess the company's profitability.

5.4 Results

5.4.1 Overview of Water Vending in the Kathmandu Valley

As the population of the Kathmandu Valley has increased, the water vending market has expanded rapidly. According to the president of the commercial source and tanking business association (VDWTEA), in the early 1990s, only 60–70 tanker trucks delivered bulk water in the valley, and no commercial water sources existed to supply tanker trucks or the bottled water vendors. The tanker truck vendors obtained water primarily from natural sources (springs and rivers). In 1994, the first commercial water source (a borehole) for use by tanker trucks was constructed in Jorpati, in Kathmandu Municipality, which was quickly followed by several additional similar enterprises. The rest of the bulk water sold by tanker truck vendors was still obtained from natural sources. The years 1996– 2000 witnessed the peak of the Maoist insurgency and the great migration from rural areas to Kathmandu, and over that short interval the water vending industry in Kathmandu boomed. The number of tanker trucks increased from 160 to 500, and many more commercial water sources (boreholes) were constructed, because many natural water sources had become depleted and contaminated. The president of the bottled water business association (NBWIA) reported much the same history.

By the time our fieldwork began in 2014, about 700 tanker trucks supplied the city with water obtained from 210 commercial water sources. Approximately 200 bottled water vendors were selling 20-L plastic jars and 1-L bottles to shops and families. A majority of the water vendors included in our vendor survey had started business after 2010. The oldest business included in the survey was established in 1992.

A great majority (88%) of the water vendors in our sample were members of one or the other of the two business associations. At time of the survey, the main role of the associations was to represent the interests and needs of the vendors to the government. There were no legal or institutional mechanisms that specify the price of vended water, quantities sold, or quality standards (Moench, 2001; Janakarajan & Moench, 2006). The business associations had issued pricing guidelines for their members, but these guidelines were not enforced. Private vendors were required to pay some taxes (such as the road and vehicle tax for tanker trucks, value-added tax (VAT) for bottled water producers, and income taxes). In addition, commercial water source vendors must obtain licenses to extract water from boreholes. Licensure abides by a national legal standard but often depends on the approval of the local community where a borehole is located (Shrestha et al., 2012). There have been ad hoc instances of government testing of the quality of water sold by different types of vendors, but as yet no systematic public sector efforts have emerged to ensure that vended water meets recognized quality standards. As a result, individual vendors have created their own water quality standards to ensure that they retain the trust of their customers and to distinguish their product from those of competitors.

Until recently, and during the time of our survey, the national law requiring licensure for commercial water vendors was not enforced. Thus, apart from costs of extraction, commercial water source vendors did not pay a price for their raw water supply, either for surface or spring water or for groundwater. In 2018, growing concerns over groundwater depletion caused the national government to consider the introduction of a licensing framework for the use of commercial water sources. As the new framework was not yet enacted, the drilling of new boreholes was put on hold, resulting in a barrier to entry into the vending market. Aware of the vital role played by the vendors in providing water to underserved Kathmandu residents, authorities remained lenient with unlicensed water extraction from the existing commercial water sources.

5.4.2 How Water and Money Flow Through the Water Vending Supply Chain

Figure 2 illustrates the water vending system in Kathmandu and how water and money flow along some of the links in the supply chain.[18] Our calculations show that during the dry season of 2014, households and businesses purchased approximately 370,000 to 500,000 m^3/month[19] from the private water market, generating total revenues for commercial water source vendors, tanker truck vendors, and bottled water vendors of about US$1 million/month. This represents about 20% of the water used by households in Kathmandu in that dry season. Commercial water source vendors sold 269,000 m^3 of water each month and received US$103,000/month from households, businesses, and tanker truck vendors. Tanker truck vendors delivered and sold 371,000 m^3 of water and received US$806,000/month, of which 31,000 m^3 was sold to retail outlets.[20] The average price of bulk water sold by tanker truck vendors was US$2.17/m^3 at the time of our study.

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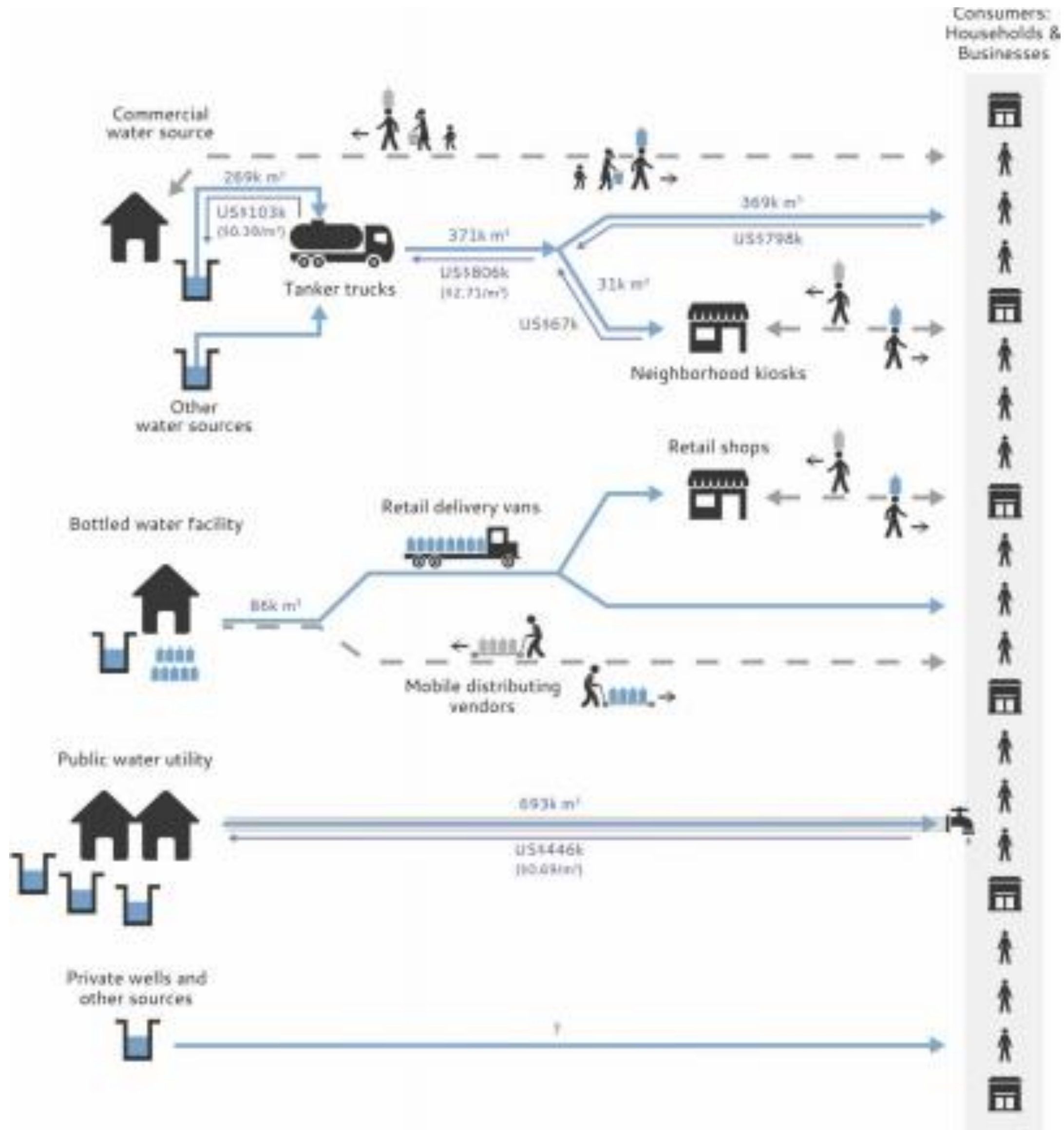
[18] Whittington et al. (1991) presented the first such water-money flow diagram for an urban area (Onitsha, Nigeria), and Whittington et al. (1993) extended such analysis to sanitation-money flows in Kumasi, Ghana. The Sustainable Sanitation Alliance has promoted the use of similar flow diagrams (but without the money flows) to describe sanitation conditions in both urban and rural areas, and these 'shit flow diagrams' are now widely used by sanitation professionals in the Global South.

[19] Estimates of the quantities of vended water vary depending on whether one extrapolates using the vending sample or the household sample. If we use data from the vending surveys, the total estimate is about 370,000 m^3/month. If we use data from the household survey, the total is about 500,000 m^3/month.

[20] There is a discrepancy in our estimates of the amount sold by commercial water source vendors (268,701 m^3) and tanker truck vendors (370,860 m^3), as we would expect the amount sold by tanker truck vendors to

Figure 5.2. Money and water flows in Kathmandu Valley, 2014 (dry season).



From our household survey, we found that the public piped water network accounted for about a quarter of total household water use (693,000 m^3/month).[21] For our sample of 1,500

be larger than that sold by commercial water source vendors. We speculate that this difference may be due to (1) tanker truck vendors drawing upon their own, noncommercial sources or (2) an underestimation of the number of commercial water source vendors.

[21] Calculated using the number of private water connections in Kathmandu Valley (194,718), as reported by KUKL. Our survey included 1,051 households using private water connections, and we calculated the average estimated volume of water collected from each connection based on household estimates.

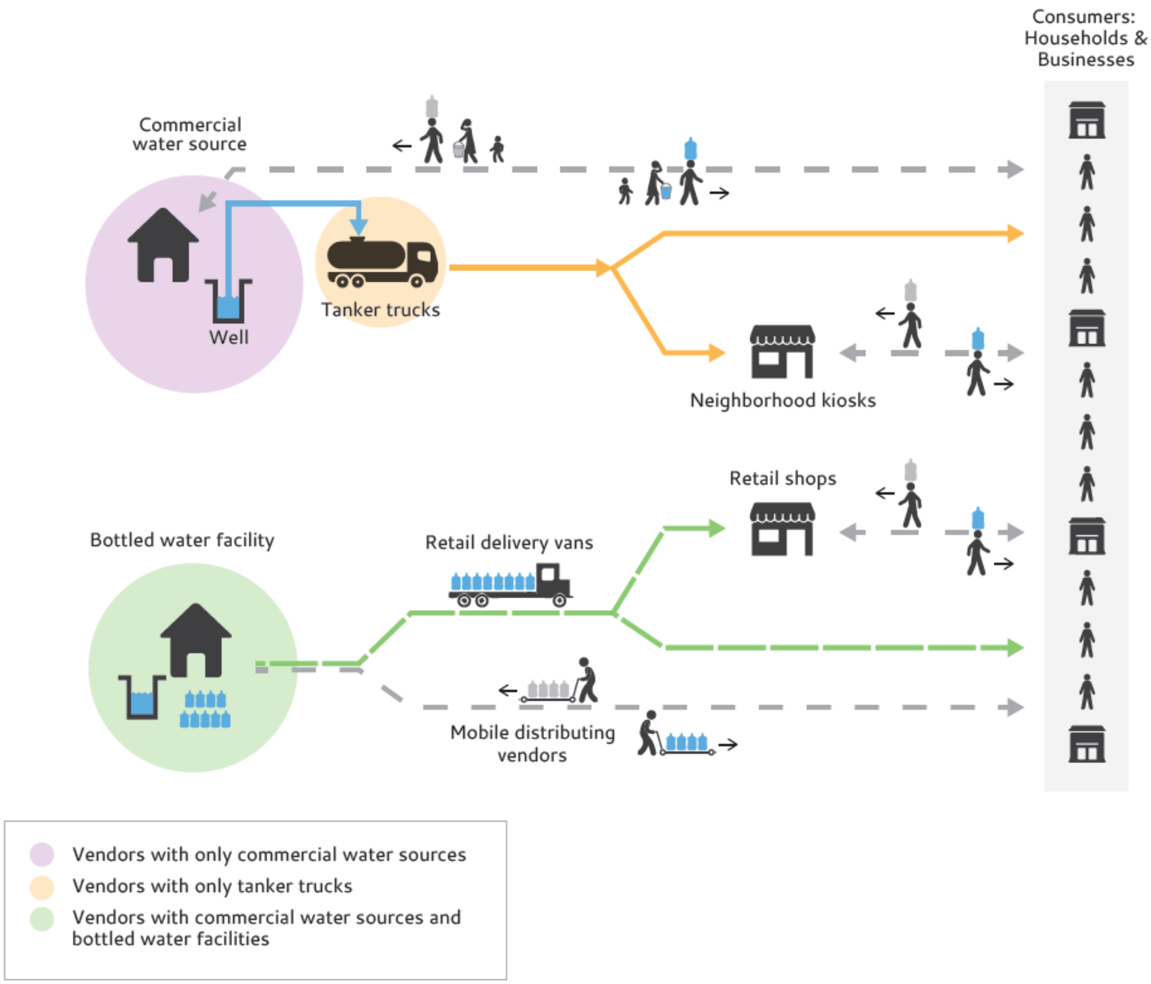
households, private wells provided 45% of the total water respondents collected and used. The piped water network supplied 26% and vendors supplied 20%. The rest (about 10%) came from other sources, such as public wells, public taps, neighbors, rainwater, ancient stone taps, and surface water.

5.4.3 Structure of the Water Vending Industry in Kathmandu Valley

5.4.3.1 Commercial Water Source Vendors

Commercial water source vendors are at the beginning of the supply chain in the water vending industry (Figure 3). These vendors abstract water from natural sources or from boreholes. They sell water to tanker truck vendors, but most also give some water gratis to households. Most commercial water source vendors (87% of our sample) also treat this water before it is loaded into tanker trucks. The most common method of treatment is sand filtration.

Figure 5.3. Water vending industry structure



Commercial water source vendors do not pay for their raw water supply but do incur capital costs for boreholes, pumps, and other facilities for delivering water to customers. Those who treat their raw water before selling to customers incur treatment costs as well. Other costs include electric, diesel, or petrol fuel for running pumps and other equipment, and labor costs for managing the facilities and sales.

In our sample, commercial water source vendors were clustered in nine areas in the Kathmandu Valley: Jorpati, Matatirtha, Swayambhu, Balaju/Bus-Park, Sundarijal, Chovar Chalnakhel, Jhaukhel, and Satdobato (Figure 1). Most (87%) offer free water to the communities within which their source is located. These vendors reported that they do so mostly to help their communities. However, our key informant interviews with government officials revealed that this policy was primarily pursued because over time, community resentment tended to grow regarding the private sale of a common resource. This rationale was corroborated in the interview with the president of the commercial vendors' business association (VDWTEA), who said that it had become extremely difficult to dig new boreholes as local people were no longer willing to give permission (as required by licensing authorities). Communities began to feel that the water source was no longer administered for the people but rather for the source vendor. Thus the provision of free water to the local community had become the norm, and families came freely to the source with their own buckets and collected water for household use. Another common practice was for the commercial water source vendor to provide the police force with one free tanker load of water per week.

Commercial water source vendors have two main options for consolidating their operations with other components of the supply chain. First, they can purchase their own tanker trucks and use those trucks to expand into the delivery of bulk water directly to households and businesses. Or, second, they can take up bottled water vending, using their commercial sources as the raw water input into more sophisticated water treatment facilities. This treated "drinking water" is then bottled into the common 20-L plastic jars and 1-L bottles for distribution to households and businesses. These two consolidation options are not mutually exclusive. Some vendors have consolidated all of these operations, covering the entire process from commercial water source extraction, to tanker truck distribution, to treatment, and bottling of drinking water.

Almost all the water from commercial water source vendors received by households in our study was delivered through tanker trucks. Only 15 of the 39 commercial water source vendors (38%) ran a source-water-only operation, selling water to other, privately-owned tanker trucks and to households. Another 46% of the commercial water source vendors in our sample had their own tanker truck operations. A few (3%) had their own bottled water operations, and 13% had both their own tanker trucks and bottled water facilities.

5.4.3.2 Tanker Truck Vendors

Vendors with tanker trucks collect water from commercial water source vendors and deliver it to both households and businesses (Figure 3). Households use bulk water for a variety of purposes. It may be used for drinking, but usually only after additional treatment (either boiling or filtering) by the households themselves. Two-thirds of the bulk water sales for tanker truck vendors in our sample were to households. Another 17% of sales were to businesses. Sales to neighborhood kiosks and to construction sites accounted for 7% each, and 2% went to hospitals.

The tanker trucks in businesses included in the survey were of varied capacities (5–15 m^3, predominantly 7 m^3). During the rainy season each vendor sold about three to four tank loads per day, thus making three to four trips back to the commercial water source to refill. During the dry season, each sold approximately twice that amount, requiring seven to eight trips per day for refilling. During the rainy season, most tanker truck vendors were able to fulfill demand within about 4 h. The same process took much longer in the dry season, with customers waiting an average of 1–2 days for their order. A large majority of tanker truck vendors (79%) reported that in the dry season they had more orders than they could fulfill.

The main operating costs for a tanker truck were fuel for the truck, and labor costs for the driver and an assistant, who helps with filling the tank at the source and discharging the tank at points of sale. A majority of tanker businesses (62%) had only one truck and employed only one driver and one driver's assistant. Owners of two trucks comprised most of the rest of the total (31%), and only a few (7%) had three trucks. A vendor who only deploys tanker trucks also incurs costs of purchasing water from a commercial water source vendor. Tanker truck vendors are also subject to taxes, fees, and regular maintenance and repairs on their trucks. Their only capital costs are expenditures to purchase their tanker trucks, and for major repairs.

A tanker truck vendor has two main options for further integration with the water vending supply chain. The first is to integrate backward along the supply chain and drill (or purchase) a commercial water source, thus both selling bulk water and self-supplying tanker(s). In our sample, 30% of the vendors with tanker trucks had their own source of water (not necessarily a commercial water source), about half from groundwater and half from surface water sources. Second, the vendor can integrate forward in the chain and begin selling bottled water (Figure 4(b)). This combined strategy enables the tanker vendor to supply bulk water to households and other businesses via tanker trucks and also to deliver higher-quality bottled drinking water directly to households and businesses (using different delivery vehicles).

5.4.3.3 Bottled Water Vendors

Vendors that produce high-quality bottled drinking water necessarily have a proprietary source for their water. Some may use natural water sources (e.g., springs), and others may use groundwater (their own boreholes).[22] Bottled water vendors often sell 20-L plastic jars of drinking water to mobile distributing vendors who, in turn, deliver them to households and businesses. The main capital costs for a bottled water vendor are the water treatment and bottling facilities and the land and building needed for these operations. They primarily use reverse osmosis technology to treat their raw water. Many in our survey used automated bottling and packaging machines (see photographs in Appendix D). Bottled water facilities also have labor costs for running and maintaining their equipment and handling sales of their product.

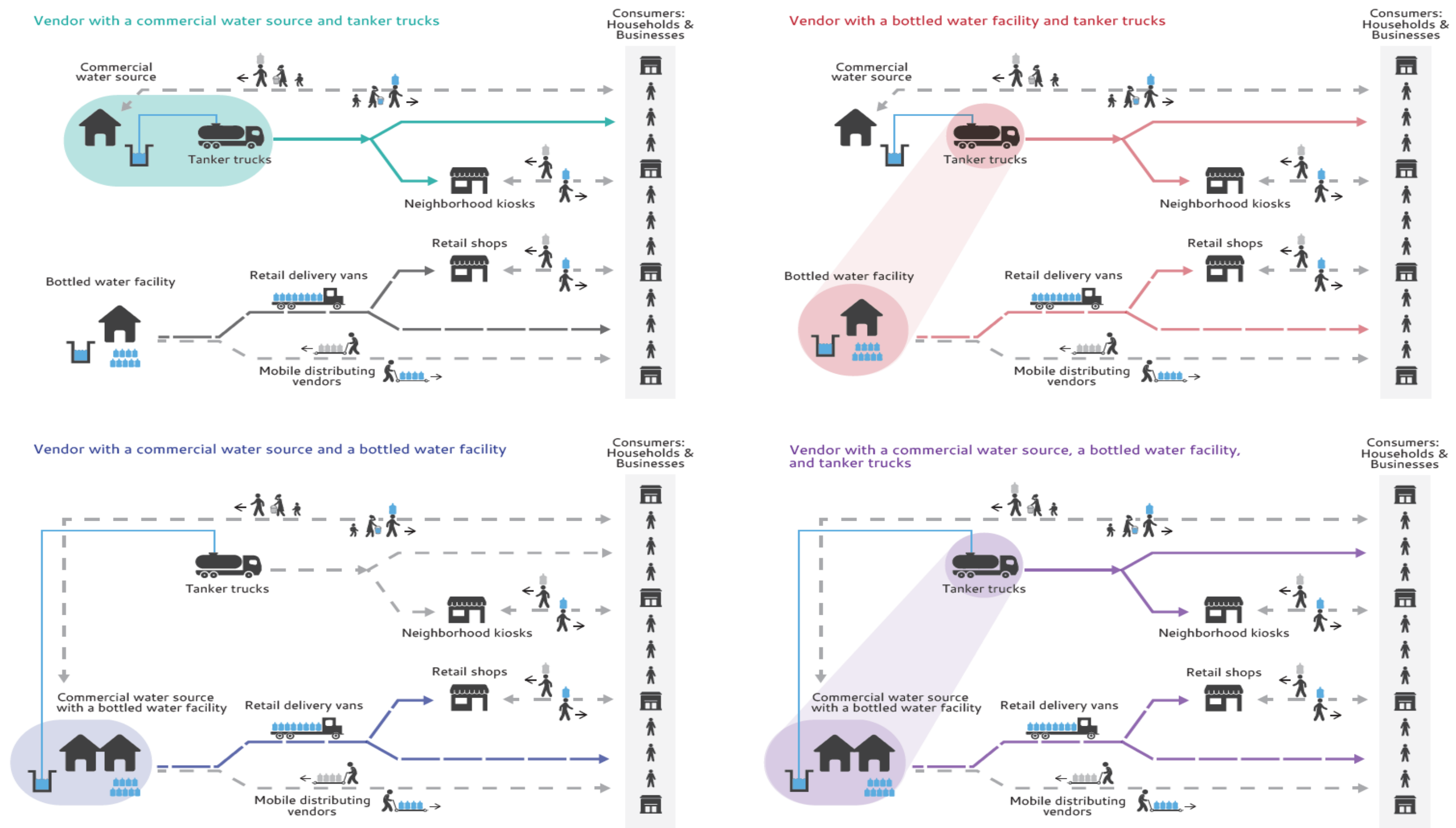
A bottled water vendor can expand by establishing its own retail distribution network, delivering water directly to households, often with motorized delivery vehicles and with its own employees. Alternatively, it can expand by supplying bulk water and operating its own fleet of tanker trucks, and/or acquire and sell bulk water from its source.

[22] It is possible that some use the public piped water distribution system.

5.4.3.4 Mobile Distributing Vendors

Our study did not include interviews with mobile distributing vendors that sell bottled water. We did learn from our household respondents and bottled water vendors that mobile distributing vendors purchase 20-L jars of water from bottled water facilities and transport these to households. In 2014, the price of a 20-L jar water was most commonly US$3.15. This price included a refundable deposit for the jar upon return. These 20-L jars can be refilled, at a price ranging from US$0.10 to US$0.74, the most common amount being US$0.32. If the household owned its jar, the mobile distributing vendor delivered a full jar and picked up an empty one.

Figure 5.4. Water vending consolidation options



5.4.3.5 Retail Outlets: Kiosks and Stores

Both bulk water and bottled water are also sold to households through retail outlets. Tanker trucks may deliver water to neighborhood kiosks, which then sell water to households in smaller quantities. The tanker truck vendor fills the kiosk's large storage containers, and from these, the kiosk vendor fills smaller containers for customers. Bottled water vendors likewise sell water to retail outlets, usually to small neighborhood stores, where households can walk to purchase 20-L jars and 1-L bottles and carry them home, or can request home delivery.

5.4.4 Entry into the Market

The oldest vending business in the sample (a tanker truck vendor) began operations in 1992. Others began to enter the market in the early 2000s. The number of vendors entering the business was greatest in 2009 and 2010, then declined up until 2014, the year of the survey. Half of the source water and bottled water vending enterprises were owned by one person. Most (79%) of the tanker truck vending businesses in our sample also were owned by one person.

Average start-up costs for a commercial water source vendor were US$76,000 (median of US$49,000 and adjusted for inflation). For a tanker truck vendor, average start-up costs were US$27,500 (median of US$20,600). For a vendor with both a commercial source and tanker trucks, average start-up costs were US$87,000 (median US$69,000). Most vendors (74%) needed to borrow money to start their businesses. Most such start-up loans came from banks (59%) or cooperatives (18%), both of which charged a median interest rate of 5% for both banks and cooperatives (range 2–10%). Friends and families also provided loans, commonly with 5% interest as well.

5.4.5 Markets Along the Supply Chain

The two main products delivered through the water vending supply chain – bulk water from natural sources or boreholes, and drinking water produced by bottled water facilities – were sold in four main markets.

Table 5.1. Description of four markets for vended water (prices in dry season)

Product	Bulk water		Bottled water	
Market	Upstream market	Consumer market	Upstream market	Consumer market
Sellers	Source owners	Tanker truck operators [a]	Bottled water operators	Bottled water operators, distributing vendors
Buyers	Tanker truck operators	Businesses, households	Distributing vendors	Businesses, households
Price (US$/m^3)				
Mean	0.38	2.25		
SD	0.08	0.57		
10th percentile	0.29	1.75		
Median	0.38	2.19		
90th percentile	0.50	2.74		

[a] Our numbers are calculated using tanker truck sales to consumers. Very few source owners sell directly to households. Large businesses often will have their own water tanker trucks, which would purchase water directly from the source.

The first of these (market 1) was the sale of bulk water from commercial water source vendors to tanker truck vendors (vendor–vendor) (Figure 3). In 2014, commercial water source vendors charged tanker trucks US$2.15 on average to fill for a 5,000 L tanker truck and US$4.86 for a 14,000 L truck. Averaging over different size tanker trucks, commercial water vendors charged tanker truck vendors an average of US$0.38/m^3 (Table 1).

Market 2 was the sale of bulk water from tanker trucks to households and businesses (vendor–end user sale). Tanker truck vendors charged households and businesses an overall average of US$2.25/ m^3, about six times the price they paid the commercial water source vendors. Charges were, on average, US$13.78 for a 5,000 L tank to US$24.73 for a 14,000 L tank. Although demand for tanker truck water was much higher in the dry season than in the rainy season, tanker truck vendors charged the same price in both seasons. It is not clear to us why they did not to raise their prices in the dry season.

Market 3 was the sale of drinking water produced by bottled water facilities to mobile distributing vendors for subsequent purchase by households and businesses (vendor–vendor). Our research protocol did not collect information permitting an estimate for the price at which bottled water vendors sold water to mobile distributing vendors. From interviews, we learned that some bottled water vendors delivered to distributing vendors for a delivery charge of between US$13 and US$16 for a minimum order of 150 20-L jars.

Market 4 was the sale of 20-L jars delivered by mobile distributing vendors and bottled water vendors directly to households and businesses (distributing vendor–end user). In 2014, the price for household delivery and exchange of a 20-L refill jar were US$0.47–US$0.63, depending on water quality and company policy. Additional market transactions occurred at kiosks for bulk tanker truck water and at neighborhood retail outlets for 20-L jars.

From the households' perspective, the water vending supply chain offered two products and six main purchase options: (1) A household member could walk to a commercial water source vendor and collect bulk water for free. (2) The household could pay a tanker truck to deliver the same-quality bulk water directly to the home, again purchasing in large quantities. (3) In some neighborhoods, households could purchase this same quality of water from kiosks in smaller quantities. (4) A household (or business) could travel to a bottled water vendor and collect 20-L jars of drinking water (with a minimum purchase). (5) A household could pay either the bottled water vendor or an independent mobile distributing vendor to deliver 20-L jars of water to the home. (6) A household could purchase 20-L jar(s) or 1-L bottles from neighborhood retail outlets and carry the water home themselves.

Figure 4 summarizes the four main ways that water vending entrepreneurs could integrate activities to serve more than one of these markets:

1. Commercial water source vendors could purchase their own tanker trucks in order to deliver water straight from the source directly to households, selling in both Markets 1 and 2. We found that this was a common integration strategy.
2. Commercial water source vendors could expand their product line by integrating bottled water vending, thus selling in Markets 1, 3, and 4.

3. A tanker truck vendor could integrate operations with a bottled water vendor, thus selling in Markets 2, 3, and 4. In 2014, this option was uncommon in the Kathmandu Valley. Only two of the vendors in our sample had adopted this integration strategy.

4. A bottled water vendor could integrate a retail distribution of 20-L bottled water into its operations, thus eliminating sales in Market 3, selling its product only in Market 4.

Additional options might have included even more aggressive integration strategies, but to the best of our knowledge, these have not yet materialized in Kathmandu.

Most of the commercial water source vendors (100%), tanker truck vendors (78%), and bottled water vendors (56%) in our sample stated that they adhered to the prices set by their business associations. However, when questioned further, the tanker truck vendors admitted they often reduced prices to fight off competition. When tanker truck vendors were asked how they priced the water they sold, 82% stated that their business association rules did not factor into their pricing decisions. In contrast, it seems that bottled water vendors used water quality instead of price to differentiate their product from that of competitors.

5.4.6 Financial Accounts for Commercial Water Source Vendors and Tanker Truck Vendors

Our data allowed us to take a more detailed look at the revenues, costs, and profits by constructing income statements for three types of vendors in the supply chain (Markets 1–3). We could then assess performance of the three types of vendors involved: (1) commercial water source vendors selling water to tanker trucks (Market 1); (2) tanker truck vendors without other vending activities (Market 2); and (3) vendors that owned both a water source and tanker trucks (Markets 1 and 2). (We did not create income statements for participants in Market 4, bottlers and mobile distributors.) To construct the income statements for sellers in Markets 1, 2, and 3 we calculated the monthly revenues, financial costs, asset productivity, and three different measures of profitability for each enterprise, in both the dry and wet seasons (Tables 3, 4, and 5). Table C.1, C.2, and C.3 present the full set of vendor-specific results.

From these income statements, we could assess the profitability of each business and compare businesses with each other. Profitability is arguably the most important criterion for evaluating the performance of a firm (Smith et al., 1998). Profitability metrics, which measure the return that the firm's owners receive from their investments, have been widely used in research on information systems, strategic management, and finance (Smith et al., 1998). There are four key metrics: return on assets (EBITDA/average assets), gross margin (direct product costs/revenue), operating margins (EBITDA/ revenue and EBIT/revenue), and net profit margin (net income/revenue) (Smith et al., 1998; Agrawal & Hall, 2014). Return on assets (ROA) is a commonly used metric for overall company performance (see Hunton et al., 2003; Andres, 2008; Adams et al., 2009). Our calculations for each vendor's income statement began with an estimate of total monthly revenue. From this we estimated four different measures of profit: (1) gross margin; (2) earned income before interest, taxes, depreciation, and amortization (EBITDA); (3) earned income before interest and taxes (EBIT); and (4) net income.

The first, gross margin, shows the profit made from making and selling a product, without taking into account overhead and other fixed costs. Gross margin is a reflection of how much value to the basic inputs is added by the company utilization of capital and technology. In competitive markets gross margins should be similar across firms, because companies with larger gross margins can lower their prices to outcompete companies with smaller gross margins. Gross margin is calculated by subtracting the cost of goods sold from monthly revenue. The cost of goods sold include only direct costs attributable to the product, including material input costs (or product costs), transportation costs (or supply chain costs), and direct labor costs. These are all variable costs; in other words, they are a function of the quantity of the product sold. For example, for tanker truck vendors, the cost of purchasing bulk water from a commercial source counts as a product cost; the fuel cost of transporting water from the source to the consumer is one component of the supply chain costs; salaries of truck drivers and truck driver assistants are direct labor costs. Our survey did not allow for direct attribution of cost of goods sold for source vendors and bottled water vendors because we did not ask these vendors how much was spent per unit produced (e.g., variable pumping costs and costs of each bottle for bottling). While we inquired about the cost of diesel, petrol, and electricity, we were unable to separate out the proportion of those costs used to pump water from the source (what would be attributed to product costs). Additionally, we did not inquire about direct labor costs for the source and bottled water vendors.

The second measure of profit, earned income before interest, taxes, depreciation, and amortization (EBITDA), provides a measure of the amount of money a company makes before accounting for the costs of capital assets and debt. It provides an idea of a company's profits independent of decisions about location (which determines taxes) and investment (in capital equipment), and it disregards sunk costs (i.e., costs already incurred that are difficult to reverse, such as drilling a borehole). EBITDA is calculated by subtracting from the gross margin the costs of selling the product, and general and administrative costs. These costs include overhead and management, maintenance and repairs, rent and utilities, and marketing and other sales costs. In our calculations, for the vendors with tanker trucks, we included, in the overhead and management category, any labor costs of staff not associated with the direct operation of tanker trucks. For source vendors, we were unable to separate direct labor from indirect labor costs and deducted all labor costs from the gross margin. For maintenance and repairs, we used estimates of monthly spending on equipment breakdowns, replacement of parts, and maintenance of trucks, equipment, pumps, and other equipment. For rent and utilities, we included the costs of renting the business premises and any other related buildings, and utility costs (electricity). We did not impute any costs for land and buildings that a business already owned. The costs of any permits, association membership, and insurance were included in "marketing and other sales costs."

The third measure, earned income before interest and taxes (EBIT), deducts from gross margin the costs of the company's capital assets. This is the operating income – that is, profits from operations, independent of debt or taxes. Debt structure can change depending upon how owners decide to raise money, access to loans, etc., and has little to do with the day-to-day operations of the business. EBIT is calculated by subtracting depreciation and amortization from EBITDA. To calculate depreciation costs, we used straight-line depreciation based on typical useful lives of different assets (see Table 2). We did not amortize intangibles such as software, etc. (Stickney et al., 2010).

Table 5.2. Useful life estimates of capital assets

Asset	Useful life
Buildings	20
Water Storage Tank/Reservoir	15
Bottling and Packaging	15
Equipment for bottled water treatment	15
Computers	5
Filters	5
Generator	15
Pumps and Piping	10
Delivery Van	10
Others: CCTV Camera	5
Tanker Truck	20

The fourth measure, "net income," shows the amount of money a company makes after deducting from revenues all costs (variable, fixed (or overhead), and sunk (difficult to reverse)), as well as taxes and interest on debt. This estimate is obtained by subtracting interest and taxes from EBIT. The interest included in our calculations was the interest on company start-up loans that were still being paid off during the time of the survey. Our survey did not ask about loans taken out after the inception of a company, so our reported interest paid constitutes a lower bound. Taxes included the VAT, income tax, vehicle and road taxes, and a village development committee (VDC) tax.

Table 5.3. Profits of vendors with only commercial water sources (dry and rainy seasons, US$/month)

Dry season	Mean	SD	10th percentile	Median	90th percentile
Revenue	942	673	404	771	2,053
Cost of goods sold					
Product costs	16	19			
Supply chain costs	228	278			
Labor costs (direct)	0	0			
Gross margin	699	692	-173	614	1,723
Selling, general, and administrative costs					
Overhead and management	95	113			
Maintenance and repairs	47	58			
Occupancy and real estate	151	106			
Marketing and other selling costs	7	10			
EBITDA	398	603	-307	296	1,254
Depreciation	415	483			
EBIT	-17	864	-1,198	75	1,058
Interest	104	252			
Taxes	6	9			
Net income	-127	852	-1,213	-195	1,048
Wet season					
Revenue	554	336	177	556	1,067
Cost of goods sold					
Product costs	16	19			
Supply chain costs	228	278			
Labor costs (direct)	0	0			
Gross margin	310	430	-271	359	883
Selling, general, and administrative costs					
Overhead and management	95	113			
Maintenance and repairs	47	58			
Occupancy and real estate	151	106			
Marketing and other selling costs	7	10			
EBITDA	9	411	-473	-10	612
Depreciation	415	483			
EBIT	405	574	-1,169	-393	371
Interest	104	252			
Taxes	6	9			
Net income	-516	521	-1,184	-574	290

Table 3 shows that water source vendors without their own tanker trucks had small mean (US$699) and median (US$614) monthly gross margins in the dry season and reduced mean (US$310) and median (US$359) monthly gross margins in the rainy season. Estimates of mean and median monthly net income proved negative for both the dry (–US$127, –US$195) and rainy (–US$516, –US$574) seasons. Figure 5(a) presents a distribution of monthly net incomes of vendors with only commercial water sources. More than half were losing money. These results suggest that commercial water source vendors without their own tanker trucks are not earning monopoly rents and appear to be operating in a very competitive market.

Table 5.4. Profits of vendors with only tanker trucks (dry and rainy seasons, US$/month)

Dry season	Mean	SD	10th percentile	Median	90th percentile
Revenue	3,836	2,230	1,971	3,057	6,859
Cost of goods sold					
Product costs	693	459			
Supply chain costs	1,656	1,464			
Labor costs (direct)	641	575			
Gross margin	846	1,268	-325	749	2,426
Selling, general, and administrative costs					
Overhead and management	99	90			
Maintenance and repairs	266	115			
Occupancy and real estate	9	36			
Marketing and other selling costs	45	23			
EBITDA	427	1,306	-683	338	2,131
Depreciation	189	156			
EBIT	238	1,263	-991	193	1,762
Interest	58	86			
Taxes	32	37			
Net income	148	1,256	-1,073	83	1,541
Wet season					
Revenue	2,035	1,175	1,061	1,629	4,093
Cost of goods sold					
Product costs	373	244			
Supply chain costs	1,051	969			
Labor costs (direct)	434	345			
Gross margin	176	809	-814	228	769
Selling, general, and administrative costs					
Overhead and management	91	91			
Maintenance and repairs	266	115			

Occupancy and real estate	9	36			
Marketing and other selling costs	45	23			
EBITDA	-235	837	-1,352	-90	493
Depreciation	189	156			
EBIT	-424	844	-1,552	-241	375
Interest	58	86			
Taxes	32	37			
Net income	-515	845	-1,564	-373	301

Table 4 presents estimates of the same measures for tanker truck vendors that were not integrated with a commercial water source. Tanker truck vendors had somewhat higher mean and median monthly gross margins in both the dry season (US$846, US$749) and the rainy season (US$176, US$228). However, our estimates of mean and median monthly net income approached zero in the dry season (US$148, US$83) and were negative in the rainy season (–US$515, –US$373). Table 4 also presents 90th percentile statistics for each variable. The measures for 90th percentile monthly gross margin (US$2,426 in the dry season) and 90th percentile monthly net income (US$1,541 in the dry season) are positive, suggesting that some tanker truck vendors were profitable. Vendors with more trucks had higher mean and median net incomes. Figure 5(b) shows the distribution of monthly net incomes for tanker truck vendors, which is centered slightly above zero. Together, these results suggest that tanker truck vendors as a whole were not earning monopoly rents and, like the commercial water source vendors, appear to have been operating in a competitive market.

Table 5.5. Profits of vendors with commercial water sources and tanker trucks (dry and rainy seasons, US$/month)

Dry season	Mean	SD	10th percentile	Median	90th percentile
Revenue	5,504	2,640	2,451	5,507	8,046
Cost of goods sold					
Product costs	144	231			
Supply chain costs	1,410	872			
Labor costs (direct)	686	283			
Gross margin	3,264	2,465	823	2,984	5,418
Selling, general, and administrative costs					
Overhead and management	216	247			
Maintenance and repairs	499	1,000			
Occupancy and real estate	301	294			
Marketing and other selling costs	49	38			
EBITDA	2,200	2,619	-1,637	2,116	4,895
Depreciation	604	465			
EBIT	1,596	2,457	-1,885	1,412	4,331
Interest	126	168			
Taxes	39	34			
Net income	1,430	2,486	-2,187	1,271	4,300
Wet season					
Revenue	3,093	1,704	1,364	2,665	5,457
Cost of goods sold					
Product costs	97	139			
Supply chain costs	991	497			
Labor costs (direct)	484	207			
Gross margin	1,521	1,579	-39	773	4,108
Selling, general, and administrative costs					
Overhead and management	212	248			
Maintenance and repairs	499	1,000			
Occupancy and real estate	301	294			
Marketing and other selling costs	49	38			
EBITDA	460	2,115	-1,787	298	3,308
Depreciation	604	465			
EBIT	-145	2,004	-2,035	-147	2,862
Interest	126	168			
Taxes	39	34			
Net income	-310	2,012	-2,336	-373	2,783

Table 5 presents estimates of the same financial measures for commercial water source vendors with their own tanker trucks. The average monthly dry season revenues of these vendors (US$5,504) are higher than monthly revenues of tanker truck vendors (US$3,836) or commercial water source vendors without tanker trucks (US$942). These vendors also had higher mean and median monthly gross margins in both the dry season (US$3,264, US$2,984) and the rainy season (US$1,521, US$773). However, although estimates of mean and median monthly net incomes are positive in the dry season (US$1,430, US$1,271), they become negative in the rainy season ("US$310, "US$373 per month). Table 5 also presents 90th percentile statistics. The 90th percentile measures for both monthly gross margin (US$5,4180) and monthly net income (US$4,300) in the dry season are positive and substantial. As with stand-alone tanker truck vendors, these results suggest that some commercial water source vendors with their own tanker trucks were profitable. These findings further suggest that integrating commercial water source vending with tanker truck vending does result in increased market power. Figure 5(c) shows that most of the vendors with commercial water sources and tanker trucks were earning net profits, with only two vendors losing significant amounts of money. Of the three types of firms, the integrated commercial water source and tanker truck vendors appear from our estimates to have been the most profitable as a whole.

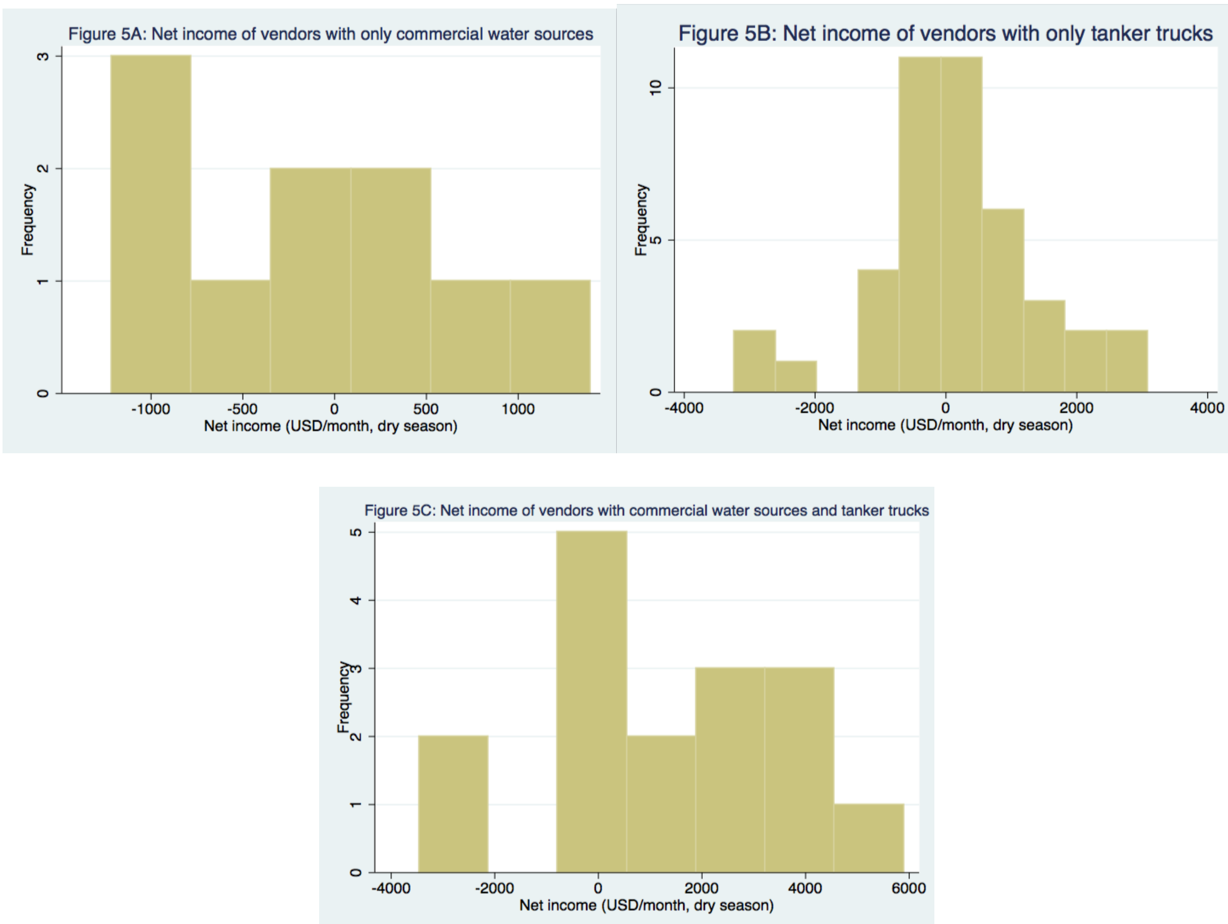
Table 5.6. Firm productivity and profitability

		Gross margin/revenue		EBITDA/revenue		EBIT/revenue	
	ROA	Dry	Rainy	Dry	Rainy	Dry	Rainy
Commercial source vendor							
Mean	0.93%	0.64	0.37	0.26	-0.37	-0.49	-1.23
SD	2.57%	0.55	0.74	0.55	1.03	1.31	1.27
10th percentile	-0.82%	-0.33	-0.83	-0.61	-1.77	-2.35	-2.34
Median	0.23%	0.85	0.67	0.46	0.06	0.05	-2.00
90th percentile	4.70%	0.96	0.95	0.76	0.67	0.73	0.55
Tanker truck vendor							
Mean	0.71%	0.23	0.10	0.10	-0.14	0.05	-0.24
SD	10.87%	0.33	0.44	0.35	0.48	0.35	0.49
10th percentile	-3.22%	-0.05	-0.25	-0.21	-0.41	-0.31	-0.56
Median	0.96%	0.25	0.14	0.10	-0.07	0.06	-0.17
90th percentile	8.47%	0.59	0.54	0.42	0.26	0.39	0.17
Vendor with commercial source and tanker truck(s)							
Mean	3.43%	0.53	0.38	0.32	-0.06	0.21	-0.28
SD	6.83%	0.22	0.28	0.38	0.82	0.39	0.86
10th percentile	-5.78%	0.31	-0.03	-0.45	-0.71	-0.52	-1.03
Median	2.07%	0.51	0.41	0.36	0.12	0.25	-0.08
90th percentile	13.37%	0.80	0.75	0.71	0.66	0.63	0.55

Table 6 summarizes vendor productivity and profitability. The average return on assets (EBITDA/assets) was less than 1% for both commercial source vendors and tanker truck vendors. However, results for vendors with both commercial sources and tanker trucks showed greater mean (3.4%) and median (2.1%) return on assets. Results for gross margins show that tanker truck vendors (Market 2) had the highest production costs, due to labor (drivers and assistants) and fuel costs, as their gross margins were the lowest (a mean of 0.23 in the dry season). Vendors with both commercial sources and tanker trucks had larger gross margins that were also more consistently positive. The standard deviation is low (0.22 compared to a mean of 0.53), indicating that the integrated vendors appear to have been operating in a competitive market. Operating margin without depreciation (EBITDA/revenue) illustrates the firm's profitability at its current level of assets. Integrated vendors with both commercial sources and tanker trucks are shown once again to be the most profitable of the three market types (0.32, compared to 0.10 for tanker truck vendors and 0.26 for commercial source vendors). Operating margin with depreciation takes into account the firm's capital investment decisions, such as the purchase of additional trucks and pumps) and reveals that many commercial source vendors were losing money, and tanker truck vendors were not profitable (with a mean operating margin of 0.05), whereas integrated vendors with commercial sources and tanker trucks remained profitable with a mean operating margin of 0.21. We did not include net profit margins in these calculations because of incomplete collection of data for interest on loans.

In summary, while there are some regulatory barriers to entry into Markets 1 and 2, such as restrictions on issuance of licenses for source vendors, these two markets appear to be quite competitive. Our estimates of net income are not excessive. There are no constraints on commercial water source vendors or tanker truck vendors regarding how much water can be extracted and sold, where their products can be sold, to whom their products can be sold, or the prices at which water can be sold. There seem to be many independent tanker truck vendors present in the market, and households purchasing from tanker trucks report that they are not dependent on any one vendor.

Figure 5.5. Distribution of vendor net income by type



5.5 Concluding Remarks

Our research shows that at the time of our study (2014), water vendors in the Kathmandu Valley operated a diverse, heterogeneous group of businesses. There was a supply chain with two main products: bulk water and bottled drinking water. Transactions occurred in four main markets: two upstream markets (between water source owners and tanker trucks, and between bottled water vendors and distributing vendors) and two consumer markets (between tanker truck vendors and consumers and between distributing vendors and consumers).

Each type of water vending business faced its own unique operational challenges and competitive pressures. Revenues, costs, and profits varied along the supply chain depending on the type, size, and integration of business operations. The characteristics of buyers and sellers also varied. Some water vendors were both buyers and sellers of water. Some water vendors were vertically integrated in the sense that they were involved in different phases in the supply chain, while others focused on only a single activity.

The portions of the water vending supply chain that we examined were all quite competitive. Yet the fact that tanker truck prices for water did not respond to substantial changes in demand between the dry and wet seasons remains puzzling. Our research also discovered two active professional associations representing different types of water vending businesses in Kathmandu. But the influence of these associations on the behavior of different types of water vendors seems to have been modest; many water vendors reported that they did not follow the pricing guidelines promoted by the associations. It appears that competitive pressures are too strong for the associations to exert price control.

Understanding the structure and complexity of the water vending supply chain is a necessary first step in developing appropriate policy responses to improve the performance of informal water markets in any area and economy where they play a part. Policy interventions such as designing governance structures and regulatory frameworks may be needed in the future to address potential negative welfare consequences resulting from water vending (Collignon & Vézina, 2000; Conan & Paniagua, 2003; Kjellén & McGranahan, 2006; Banerjee, et al., 2011). Such interventions can be targeted toward parts of the water vending supply chain where efficiency gains are most feasible and competition is most vulnerable. However, our research has not uncovered problems that would appear to require urgent attention.

Indeed, water vendors in the Kathmandu Valley have played a crucial role in filling the water supply and demand gap that arose first historically, then critically in recent years, from inadequate public water supply. Approximately 20% of the water for households and business use in the Kathmandu Valley is delivered by this water vending supply chain. However, these water vending services have not been cheap. In the dry season, end users of vended water (both tanker truck water and bottled water) pay approximately 3.4 times as much for vended water as they pay for water from the public piped water distribution system.

These large amounts of money flowing through the water vending supply chain illustrate the revenue potential associated with improved services offered by the public piped distribution system. In Kathmandu, at the time of our writing (2018), the Melamchi Water Supply Project is nearing completion. There is the possibility that KUKL will be able to improve the quantity and quality of the water supplied through the piped water system. The results of our research suggest that most households are already paying much more to water vendors than to KUKL, and that the completion of the Melamchi Water Supply Project offers KUKL a rare opportunity to raise water tariffs simultaneously with the delivery of improved piped services.

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CHAPTER 6: A META-ANALYSIS OF HEDONIC PROPERTY VALUE MODEL ESTIMATES OF PIPED WATER SUPPLY SERVICES IN DEVELOPING COUNTRIES

6.1 Introduction

Extending access to improved water services continues to be a development priority for international policymakers and local governments, as demonstrated by high-profile target setting through the Millennium Development Goals and the more recent Sustainable Development Goals. Piped supply is an important improved water service, providing water to 4.7 billion people (64% of the global population) in 2015 (WHO and UNICEF, 2017). To understand the benefits of extending access to piped water, household demand for piped water supply needs to be estimated.

The hedonic property value model (HPVM) is frequently used to estimate the economic value of a wide range of environmental amenities, especially when designing and analyzing policies. Much work has been done in high income countries, where the large data requirements are more easily fulfilled and housing markets are competitive. For example, it has been used to value clean air (Chay & Greenstone, 2005; Smith & Huang, 1995), freshwater lake protection (Boyle, Poor, & Taylor, 1999), the impact of global warming on US agriculture (Mendelsohn, Nordhaus, & Shaw, 1994; Schlenker, Hanemann, & Fisher, 2005; Deschênes & Greenstone, 2007), and more.

Hedonic literature in low and middle income countries is less developed and remains not systematically well understood. The HPVM is used to estimate household (marginal) willingness to pay for piped water in developing countries but reports a wide range of estimated market premiums for piped water. As housing markets can be very different in low and middle income countries, we cannot expect the HPVM to perform as it does in high income countries. The accuracy, validity, and reliability of the HPVM as a non-market valuation tool for piped water supply calls for not only the careful application of the method but also a nuanced understanding of the complexities of piped water supply.

While comprehensive reviews have been conducted for stated preference (SP) studies on household demand for improved water services (see Van Houtven et al. (2017) for a meta-analysis), there has not been one conducted for revealed preference (RP) studies. RP methods in general have not faced the same level of "aggressive scrutiny" applied to SP methods (Bishop and Boyle, 2019), leading to a need for increased assessments around the validity and reliability of RP methods. As a result, our study fills this gap and focuses specifically on its application in the developing country context. We conduct the first meta-analysis of estimates of household water demand derived from the hedonic property value model,[23] allowing us to identify the common challenges and solutions for improving the accuracy of the hedonic method when used to value piped water supply in low and middle income countries.

Our meta-analysis makes two important contributions. First, through the meta-analysis, we comprehensively review and synthesize the results from HPVM studies. We examine the significance and magnitude of market premiums estimated by HPVM studies in relation to study characteristics. There does not exist a general consensus around research methods and design, and the choice of research procedures affects both the significance and magnitude of market premiums for piped water supply. We find that existing hedonic estimates of the value of piped water supply in low and middle income countries are broadly unreliable and vary widely, with monthly market premiums ranging from –$1.26[24] per month to $938 per month, with an average value of $66 (median, $3.12). There are many implausibly large market premiums, right skewing the

[23] Komives (2003) comprehensively surveys the literature on the role of infrastructure in the hedonic price schedule in her unpublished Ph.D. dissertation. Although the study provides a strong basis for synthesizing the results, it does not focus on water specifically and does not investigate the robustness of results using regression models.

[24] All dollar values in paper are 2017 PPP USD.

distribution of estimates. We also find that 37% of estimated hedonic coefficients on piped water services are not significant.

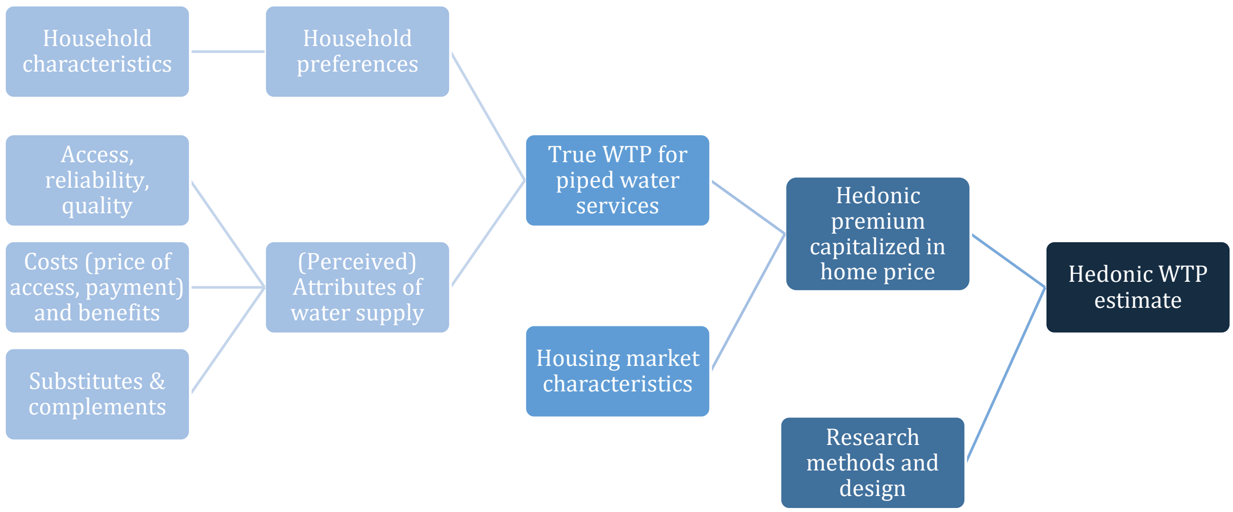
Second, we compare the results to those from SP and coping cost studies to assess validity. We find that while the median values elicited from HPVM are expectedly larger than those found in SP studies, the median values are double those found in a few coping cost studies and mean hedonic premiums are implausibly large and not consistent with expectations. However, there are still many hedonic studies that estimate market premiums that are reasonable and well-designed. We follow this assessment with suggestions for best practices for future work.

In the next section, we present an overview of the hedonic method as applied in low and middle income countries and the expected challenges when estimating household values of piped water supply. In Section 3, we present the methods used in this paper – an explanation of the meta-analysis and data collection procedures. In Section 4, we present the meta-regression model. Section 5 presents the results from the meta-analysis and explains the heterogeneity of market premiums for water services found in the literature. We provide a discussion of the results in Section 6, assessing the reliability and validity of the hedonic method. We conclude with Section 7 by identifying common challenges and best practices for future work.

6.2 Using the Hedonic Property Value Model to Value Piped Water Supply

Theories of the HPVM and water demand guide the identification of drivers of differences in hedonic market premium estimates for piped water. Figure 1 provides a theoretical framework for our meta-analysis. It illustrates how drivers first affect the true household WTP for piped water services and the subsequent hedonic WTP estimate. These drivers can then be functionalized as independent variables explaining the marginal willingness to pay estimates.

Figure 6.1. Determinants of hedonic willingness to pay for water supply services estimates



In our framework, we first turn to the true WTP for piped water services. Two basic factors determine a household's demand for piped water services: (1) household preferences that can be shaped by household characteristics (e.g., household size, income) and (2) attributes of the piped water services (e.g., access, reliability, water quality, and costs and benefits) and other types of water supply available that may be substitutes or complements (e.g., private wells, vended water) (Nauges and Whittington, 2009). For instance, we understand that income elasticity is positive, but low (Nauges and Whittington, 2009). The characteristics of the water supply are also important. We would expect unreliable water supply of poor quality to elicit a lower marginal WTP than a piped network supplying 24/7 available, potable water. The presence of alternative water supply, such as from private wells, water vendors, and public taps, will also affect marginal WTP for piped water.

How the household's true WTP for piped water services is then capitalized into the home price depends on the local housing market characteristics. For example, when the housing market is not in equilibrium (e.g., due to an economic downturn or large swings in housing prices), home prices are not likely to represent market prices (Coulson and Zabel, 2012; Riddel, 2004; Leamer, 2007). The large ranges of hedonic estimates seen in meta-analyses of Superfund sites (Kiel and

Williams, 2007) and air pollution (Smith and Huang, 1995) can be attributed to these disequilibrium effects (Coulson and Zabel, 2012).

Finally, the measurement of the hedonic premium that is capitalized in home price can also affect the resultant hedonic WTP estimate. The choice of research design and methods used, such as the functional form of the hedonic price function or adjustments for spatial effects can have important and significant effects on the final hedonic estimate measured by researchers (Taylor, 2003).

With this framework in mind, we review the HPVM as applied in the high-income country context. We have two objectives: (1) to assess the ability of the HPVM to provide reliable and accurate estimates and (2) to learn from their experiences by identifying both "best practices" and challenges. We then discuss the implications of and challenges expected when using the HPVM to estimate marginal WTP for piped water in low and middle income countries.

6.2.1 Hedonics of Water Provision and Contamination in the United States

The HPVM has been frequently used in high income countries to value water resource related amenities of three types: recreational and aesthetic value of water bodies (Lansford and Jones, 1995; van Dijk et al., 2016); access to irrigation water (Selby, 1945; Hartman and Anderson, 1962; Faux and Perry, 1999; Schlenker, Hanemann and Fisher, 2007; Petrie and Taylor, 2007; all reviewed in Buck et al., 2014); and water quality, including both local environmental quality (Mendelsohn et al., 1992; Michael, Boyle, and Bouchard, 1996; Boyle, Poor, and Taylor, 1999; Leggett and Bockstael, 2000; Gibbs et al., 2002; Poor et al., 2010) and disamenities related to drinking water contamination (Boyle et al., 2010; Zabel and Guignet, 2012; Guignet, Walsh, and Northcutt, 2016; Christensen et al., 2019). As most homes in high income countries are connected to a water supply network, non-market valuation research has instead focused on estimating demand for "water quality, water service reliability, and water resource protection issues" (Zhang and Fogarty, 2014). Of the hedonic literature in high income countries, studies valuing disamenities of drinking water contamination are those most closely related to estimating demand for piped water supply in low and middle income contexts; both contribute to estimates of the value of reliable and good-quality drinking water for households in private residences. While these measures are related, empirical measures valuing disamenities in high income countries should not be used to benchmark hedonic estimates valuing amenities from middle and low income countries, as not enough is understood about how to compare relative magnitudes of hedonic premiums.[25] Instead, we focus on learning from high income country studies about causal pathways between characteristics of water supply and home value as well as the application of the hedonic method.

Empirical studies of water contamination find varying effects on home prices (see Table 1 and Appendix E for more detailed discussion). Evidence from the United States suggests that groundwater contamination can be capitalized in home prices under three conditions (also reviewed by Patchin (1988, 1992) and Mundy (1992) in Dotzour (1997)): (1) when drinking water is affected, (2) when significant expenditures must be made to avert the effects of drinking water contamination, and (3) public and home buyer perceptions are important. They find, however, that the effect of contamination disappears after mitigation efforts or when it is no longer reported in

[25] We expect there to be a difference between the willingness-to-accept the loss of an amenity (e.g., water contamination) and the willingness-to-pay for the same amenity (e.g., clean water). The difference has been attributed to (1) the income effect, (2) the substitution effect (Hanemann, 1991), and (3) loss aversion (Zhao and Kling, 2001). First, all things equal, we expect WTP to be higher in high income countries due to the income effect. Second, we expect WTA > WTP due to the "endowment effect" and "loss aversion" (e.g., Kahneman et al. (1990)). The income effect predicts that the WTA/WTP ratio is higher in middle and low income countries than in high income countries. With more substitutes for piped water supply available in middle and low income countries where there is poor water supply, we would expect that the WTA/WTP ratio to be higher in high income countries and therefore amplify the difference between the WTA in high income countries and WTP in middle and low income countries. However, it is unclear which effect dominates – the income or substitution effect. Therefore, we generally expect WTA water contamination in high income countries to be larger than WTP for clean water in middle and low income countries. But studies in middle and low income countries rarely estimate hedonic premiums for only clean water. Estimates are often provided for a piped water connection, which may or may not provide both a clean and reliable water supply. As a result, it is difficult to compare relative magnitudes of hedonic premiums from high income countries with those from middle and low-income countries.

the media. These conditions are related to the attributes of water supply and its perception (Figure 1).

First, the effects are significant when drinking water is directly affected (i.e., quality of drinking water supply in Figure 1). Boyle et al. (2010) and Guignet, Walsh, and Northcutt (2016) study homes that use private wells. Groundwater contamination therefore affects the household water supply. Lead contamination in Flint, Michigan, had demonstrated health effects in those using the municipal water supply, particularly children (Grossman and Slusky, 2017; Hanna-Attisha et al., 2016). In one of the earlier studies (Dotzour, 1997) where the groundwater contamination did not affect piped water supply and no immediate threat to health was perceived, there were no significant effects on home prices. Boyle and Kiel's (2001) review of 30 papers also corroborates this point: they find that while the impacts of environmental externalities on house prices are generally statistically significant and have the correct sign, estimated dollar values fluctuate and measures that obtain the best results "seem to be those that would be most easily observed by individuals."

Second, capitalization can occur when property owners must make significant expenditures in averting the effects of contamination (i.e., the costs of water supply in Figure 1). This can be one explanation for the temporary effects documented by Case et al. (2006), Boyle et al. (2010), and Guignet, Walsh, and Northcutt (2016). Successful and complete homeowner or government mitigation of the groundwater contamination can partially explain why home prices rebound and no statistically significant effect remains. Homeowners can install point of use filtration systems (Boyle et al., 2010); governments can implement successful mitigation strategies, including connecting homes to uncontaminated municipal sources (Page and Rabinowitz, 1993; Case et al., 2006; Guignet, Walsh, and Northcutt, 2016). Finally, public and home buyer perceptions are important, demonstrated by the documented effects of publication of contamination (Page and Rabinowitz, 1993; Case et al., 2006).

Table 6.1. Effect of water contamination on home prices in the United States

Paper	Study site	Water source	Contaminant(s)	Effect on home prices	Time effects	Author explanations	R2
Malone & Barrows (1990)	Portage County, Wisconsin	Private wells	Nitrogen and aldicarb	No significant effect	N/A	Lack of capitalization from sellers delaying sales but not decreasing sale prices. Buyers who care greatly about nitrate levels may avoid the study area and locate to a place with public water supply.	0.70-0.74
Page & Rabinowitz (1993)*	Barton, Wisconsin	Private wells	VOCs	No significant effect for residential property owners	N/A	Town and state government closed the municipal landfill, brought tanker trucks of potable water, and connected affected residences to a new municipal water line. Residential property owners perceive minimal risk of liability for environmental cleanup or mitigation. Additionally, appraisers do not ask about the presence of hazardous substances and brokers avoid	N/A

						discussing these issues.	
Dotzour (1997)*	Wichita, Kansas	Piped network	VOCs	No significant effect	N/A	Home buyers did not believe they would be responsible for cleanup costs. The contaminated groundwater was also not a source for the public water supply system.	N/A
Case et al. (2006)	Scottsdale, Arizona	Piped network	VOCs	4.7% decrease	Decrease occurs after contamination becomes publicly known; effect disappears after 5 years.	Decrease in effect attributed to a decline in the market value of clean groundwater; local water providers also immediately stopped using contaminated water source and began remediation efforts.	0.32
Boyle et al. (2010)	Buxton and Hollis, Maine	Private wells	Arsenic	0.5-1.0% decrease for each 0.001 mg/L of arsenic above the regulatory standard of 0.050 mg/L, with average of 0.086 mg/L in private wells	Effect disappears after 3 years.	Decrease in effect attributed to (1) installation of in-home water treatment systems or (2) dissipation of perceived risk once media coverage stopped.	0.33-0.39

Guignet, Walsh, and Northcutt (2016)	Lake County, Florida	Private wells	Nitrogen, arsenic, and ethylene bromide	2-6% decrease when contamination exceeds health standards; 15% decrease at contamination levels twice the standard	Effect diminishes over time.	Decrease in effect attributed to state-wide mitigation strategy, which included connecting homes to uncontaminated municipal sources.	0.77-0.82
Christensen et al. (2018)	Flint, Michigan	Piped network	Lead	33% decrease	Crisis is on-going, long-term effects are unclear.	Large effect could be due to the difficulty in separating the effect of lead contamination from systematic governance failures.	N/A

*Not hedonic studies, but examined the effect of water contamination on property values.

Boyle and Kiel (2001) highlight three other general, methodological points in their review of hedonic methods (falling into the "Research methods and design" box in Figure 1). First, neighborhood variables are important when water quality is poor (Epp and Al-Ani, 1979). Additionally, including multiple measures of water quality can be problematic due to high correlation between measures (Steinnes, 1992; Michael, Boyle and Bouchard, 2000; in Boyle and Kiel, 2001). Boyle and Kiel (2001) find that research is often conducted over short periods and are therefore generally unable to capture changes in price over time.

Hedonic studies of drinking water contamination in the United States can also provide a comparison for how well the models perform, i.e., how much of the variation the models can explain. We find that the model R^2 of these studies range from 0.32 to 0.82 (see Table 1).

6.2.2 Expected Challenges to the Accuracy of the HPVM: A Special Case of Piped Water in Developing Countries

Findings from the United States suggest that water supply could be frequently capitalized into home values in developing countries as drinking water supply often has issues and requires significant individual investments to cope with poor water supply conditions. However, inferences drawn from high income studies need to be qualified. First, there can be different household preferences and how attributes of water supply are perceived by the public and home buyers (Figure 1).

Additionally, the nature of water supply in developing countries complicates the application of the hedonic method. While water is commonly assumed to be a "homogeneous good that has no direct substitute or complement" in industrialized countries, water in developing countries is heterogeneous, with multiple sources (i.e., substitutes and complements) that differ in conditions of access (distance to source and price), reliability, and quality, as well as costs and benefits (Nauges and Whittington, 2009). Demand for water is affected by these issues. Not accounting for them can lead to (1) biased and inefficient estimates and (2) muddled policy implications.

In Figure 1, the first group of attributes of piped water supply includes access, reliability, and quality. These three characteristics can vary greatly between and within cities; we expect them to have effects on the hedonic premium and its interpretation. First, access to piped supply within cities is often not universal. When overall access to piped water supply in a city is low, the benefits of having a connection may include a status premium. When overall access is high, the costs of not having a connection may include a willingness to accept a disamenity. We would also expect selection effects to be stronger when access is extremely low or high. Second, the reliability of water supply can also vary – with both planned and unplanned service disruptions. With longer disruptions, households may need to install storage tanks and pumps, resulting in significant expenditures in order to cope with the supply conditions. Capitalization may occur as a result of these expenditures. Third, water characteristics also vary, in terms of color, taste, smell, temperature, and contaminants with negative health impacts. It is important to understand household and home buyer perceptions, particularly with respect to contaminants that affect human health.

These complexities affect the interpretation of the hedonic market premium and its comparison between papers. A piped water connection can mean 24/7 provision of potable water or only a few hours every couple of days, with water that then needs to be boiled and/or filtered. Differences in water supply characteristics are not limited to the present – expectations about future changes in piped water service availability, reliability, and quality may also affect market premiums. We expect capitalization effects to be strongest in cities that have large variations in water service delivery access, reliability, and quality and resulting variations in household level mitigation strategies (i.e., coping behaviors and expenditures).

Price of service delivery (i.e., water tariffs and connection fees) and the availability of alternative water sources also affect household piped water demand and perhaps capitalization into home prices too. Market premiums for piped water connections should also be related to the payment for piped water services, which includes the connection fee and monthly water bills. All things equal, we expect market premiums for piped water connections to be lower in cities where connection fees are lower. Market premiums would also be higher in cities with restrictions on new connections. Similarly, we would expect market premiums to be higher in cities where water tariffs are lower than utility supply costs and can be thought of as providing untargeted subsidies to households (Komives et al., 2005). It therefore important to understand how households pay their water bills. If it is included in their rent, the market premium would then include the monthly water bill. For those that do not pay a monthly water bill, the market premium would encompass not only the marginal demand for access to the piped water network but also the value of the "free" water obtained through the connection. In addition to costs related to water utility prices for access and usage, households could also face additional costs for installing in-home piped water connections – storage tanks, pumps, and plumbing. Depending on local contexts, comparable homes, and preferences, these costs could be priced into the home value.

Together with the true WTP for piped water services, housing market characteristics affect the hedonic premium capitalization in home price. We also expect there to be differences when applying the HPVM in low and middle income countries compared to high income countries because housing markets can be very different. For example, housing markets may not be active, competitive, and in equilibrium (Malpezzi, 1999). Mobility of households – therefore market activity – varies greatly in developing countries, from 3% to 43% (Strassman, 1991; Malpezzi, 1999). Tenure security, not always guaranteed and systematically affecting housing prices, also affects mobility and market activity (Friedman et al., 1988). Systematic differences in housing supply factors can also introduce heterogeneity in markets. These factors include: accessibility of housing finance and mortgage rates, prevalence of informality in land markets, government allocation of land and subsidies (Malpezzi, 1999). When applying the HPVM, these conditions are necessary for (1) the home price to reflect home and neighborhood characteristics and (2) to interpret the derived marginal implicit prices as marginal willingness to pay.[26] As a result, we cannot expect that the HPVM will perform similarly in low and middle income countries.

Research design and methods affect the measurement of the hedonic premium that is capitalized and, as a result, the hedonic WTP estimate. With respect to research design, endogeneity in the form of simultaneity can be a large concern. As mentioned before, the allocation of water services can be influenced by political power and wealth. The "elite-focused culture of governance" is a significant and well-recognized issue in water services provision (Bakker et al., 2008; Tiwale et al., 2018; Alda-Vidal et al., 2018). Simultaneously, access to water services can affect home prices. Estimating only one portion of the model results in endogeneity and therefore biased estimates of the market premium. As a result, simultaneity is of particular importance in estimating market premiums for piped water services. However, this has not been addressed adequately in the literature, as none of the authors reviewed have accounted for this type of endogeneity.

There are many methodological choices that researchers make that can affect the measurement of the hedonic premium. Based on the complexities of water supply described above, we expect that (1) the measurement of piped water services and home value, and (2) the treatment of omitted variables to be important. Heterogeneity across piped water supply characteristics creates two problems when researchers use a simple binary variable. First, it can introduce measurement error, which can result in a downward bias of the coefficient, as well as omitted variable bias. Second, it affects the interpretation of the results for policy-makers. It is important to understand clearly for what the residents are paying in order to make comparisons across study sites. Market premiums could differ because the environmental attribute being valued is different.

[26] Marginal implicit prices are estimates of marginal willingness to pay under two main conditions: (1) households are in equilibrium given the vector of housing prices and (2) the vector of housing prices clears the market for the given stock of housing (Taylor, 2014). Further requirements include full information on all housing prices and attributes; transaction and moving costs at zero; and price vectors that adjust instantaneously to changes in supply or demand (Taylor, 2014).

All else equal, we would expect market premiums to be higher for piped water connections that provide reliable and clean water at an affordable price (with few available substitutes) when compared to those that provide contaminated water with frequent service disruptions at high prices (with many available substitutes). Indeed, Michael, Boyle, and Bouchard (2000) demonstrate that the measurement of environmental quality matters (and can result in large differences in implicit prices) and should not be selected due to convenience. The measurement of home value is also important – whether it is a sale price or rental price has different implications for the interpretation of the hedonic premium. Omitted variables can include the use of other water sources, the presence of a storage tank, or other infrastructure variables. We discuss these issues in greater depth in the methods section below.

6.3 Methods

Meta-analysis is used to synthesize results from many individual studies and explain the differences in results between the studies. Meta-analyses allow researchers to extend beyond qualitative literature reviews by providing a "rigorous statistical synthesis of the literature" (Woodward and Wui, 2001). In environmental economics, meta-analysis has been leveraged to interpret non-market valuation studies across many topics: outdoor recreation, air pollution, recreational fishing, visibility, health risks, endangered species, and wetlands (Smith and Kaoru, 1990; Brouwer, 2000; Brouwer et al., 1997; cited in Woodward and Wui, 2001).

We use a meta-analysis to evaluate the reliability and validity of using the hedonic method to estimate the true willingness to pay for piped water services. By first collecting the estimates and examining procedures chosen by researchers, we can examine the HPVM's reliability. We see if there is a consensus on basic procedures and econometric approaches, which would provide a test for content validity. The meta-regression analysis can then be used to evaluate the effects of (1) different research design and method choices when applying the HPVM and (2) attributes of water supply, households, and housing markets on the significance and magnitude of the price premium for water services. It is often not possible to understand these effects in the context of a single study because many of these attributes are often held constant in a single study (Woodward and Wui, 2001). Our basic approach is the same as that used in most valuation meta-analyses.

We collect a set of primary studies with a common empirical outcome – the market premium, or marginal willingness-to-pay, for piped water services in the home – which then becomes the dependent variable in our meta-analysis. We use the market premium as a proportion of home value, a relative measurement instead of an absolute one (such as the market premium expressed as 2017 PPP USD per month). We choose the relative measure because (1) it is most frequently a directly outcome from hedonic models and (2) it is the measure of choice in other meta-analyses, described as "[comparably more] robust to inflation and differences between local markets" (Braden et al., 2011; Nelson, 2004).

Table 6.2. Hedonic valuation studies - results

Study	Study population (site, year)	Water services variable	Signif.	Market premium[1] % home value	2011 PPP USD/month	% income
Asabere (1981)	Lot owners (Accra, Ghana, 1974-1978)	Site services (at least one of access to water, electrical, road, site preparation) (0,1)	NS	15.0%	-	-
Quigley (1982)	Low-income homeowners (Santa Ana, El Salvador, 1976)	Presence of running water (0,1)	**	12.5%	3	1.3%
Jimenez (1982)	Low-income homeowners and squatters in slums (Manila, Philippines, 1978)	With a sink (and a water connection) (0,1) as a "proxy for individual water connection"	NS	39.9%	41	7.7%
Jimenez (1984)	Homeowners (Davao, Philippines, 1979)	Water facilities index	NS	1.7%	1.3	0.1%
Jimenez (1984)	Renters (Davao, Philippines, 1979)	Water facilities index	NS	1.7%	2	0.2%
Friedman, Jimenez & Mayo (1988)	Renters and squatters (Manila, Philippines, 1983)	Sink (0,1)	**	50.0%	-	-
Friedman, Jimenez & Mayo (1988)	Owners and squatters (Manila, Philippines, 1983)	Sink (0,1)	**	20.4%	-	-
Megbolugbe (1989)	Single family home dwellers (Jos, Nigeria, 1981)	Piped water (0,1)	NS	7.0%	283	-
Megbolugbe (1989)	Multi-family home dwellers (Jos, Nigeria, 1981)	Piped water (0,1)	**	3.4%	11	-
Arimah (1992)	Renters (Ibadan, Nigeria, 1988)	Piped water (0,1)	NS	1.0%	0.5	0.3%
Aryeetey-Attoh (1992)	Low-income renters (Rio de Janeiro, Brazil, 1983)	Piped water (0,1)	**	64.9%	-	-
Aryeetey-Attoh (1992)	Middle-income renters (Rio de Janeiro, Brazil, 1983)	Piped water (0,1)	NS	1.0%	-	-
Aryeetey-Attoh (1992)	Upper-income renters (Rio de Janeiro, Brazil, 1983)	Piped water (0,1)	**	63.2%	-	-
North & Griffin (1993)	Low-income homeowners (Bicol Region, Philippines, 1978)	Piped water in home (0,1)	*	47.0%	9	2.5%
North & Griffin (1993)	Middle-income homeowners (Bicol Region, Philippines, 1978)	Piped water in home (0,1)	*	47.0%	16	1.7%
North & Griffin (1993)	High-income homeowners (Bicol Region, Philippines, 1978)	Piped water in home (0,1)	*	50.0%	14	0.7%

Daniere (1994)	High-income homeowners, with household size > 7 (Manila, Philippines, 1983)	Access to piped water within the structure/lot (0,1)	NS	37.2%	63	6.4%
Daniere (1994)	High-income homeowners, with household size < 7 (Manila, Philippines, 1983)	Access to piped water within the structure/lot (0,1)	NS	60.0%	101	10.4%
Daniere (1994)	High-middle-income homeowners, with household size > 7 (Manila, Philippines, 1983)	Access to piped water within the structure/lot (0,1)	NS	-23.2%	-39	-4.0%
Daniere (1994)	High-middle-income homeowners, with household size < 7 (Manila, Philippines, 1983)	Access to piped water within the structure/lot (0,1)	*	48.6%	82	8.4%
Daniere (1994)	Low-middle-income homeowners, with household size > 6 (Manila, Philippines, 1983)	Access to piped water within the structure/lot (0,1)	NS	22.1%	37	3.8%
Daniere (1994)	Low-middle-income homeowners, with household size < 6 (Manila, Philippines, 1983)	Access to piped water within the structure/lot (0,1)	*	25.6%	43	4.4%
Daniere (1994)	Low-income homeowners, with household size > 6 (Manila, Philippines, 1983)	Access to piped water within the structure/lot (0,1)	NS	10.8%	18	1.9%
Daniere (1994)	Low-income homeowners, with household size < 6 (Manila, Philippines, 1983)	Access to piped water within the structure/lot (0,1)	NS	0.1%	0.2	0.0%
Daniere (1994)	High-income squatters, with household size > 7 (Manila, Philippines, 1983)	Access to piped water within the structure/lot (0,1)	NS	279.7%	146	29.3%
Daniere (1994)	High-income squatters, with household size < 7 (Manila, Philippines, 1983)	Access to piped water within the structure/lot (0,1)	*	78.2%	41	8.2%
Daniere (1994)	High-middle-income squatters, with household size > 7 (Manila, Philippines, 1983)	Access to piped water within the structure/lot (0,1)	NS	72.9%	38	7.6%
Daniere (1994)	High-middle-income squatters, with household size < 7 (Manila, Philippines, 1983)	Access to piped water within the structure/lot (0,1)	*	238.4%	124	25.0%
Daniere (1994)	Low-middle-income squatters, with household size > 7 (Manila, Philippines, 1983)	Access to piped water within the structure/lot (0,1)	NS	-64.3%	-34	-6.7%
Daniere (1994)	Low-middle-income squatters, with household size < 7 (Manila, Philippines, 1983)	Access to piped water within the structure/lot (0,1)	NS	-15.4%	-8	-1.6%

Daniere (1994)	Low-income squatters, with household size > 6 (Manila, Philippines, 1983)	Access to piped water within the structure/lot (0,1)	NS	-39.4%	-21	-4.1%
Daniere (1994)	Low-income squatters, with household size < 6 (Manila, Philippines, 1983)	Access to piped water within the structure/lot (0,1)	NS	20.2%	11	2.1%
Akpom (1996)	Renters (Lagos, Nigeria, 1988)	Steady supply of piped water (0,1)	**	0.7%	3	-
Crane, Daniere, & Harwood (1997)	Low-income homeowners in slums (Bangkok, Thailand, 1993)	Piped water (0,1)	**	135.6%	938	71.7%
Crane, Daniere, & Harwood (1997)	Low-income renters in slums (Bangkok, Thailand, 1993)	Piped water (0,1)	**	352.7%	832	63.6%
Crane, Daniere, & Harwood (1997)	Low-income squatters in slums (Bangkok, Thailand, 1993)	Piped water (0,1)	NS	58.6%	145	11.1%
Crane, Daniere, & Harwood (1997)	Low-income homeowners (Jakarta, Indonesia, 1993)	Piped water (0,1)	NS	81.7%	434	-
Crane, Daniere, & Harwood (1997)	Low-income renters (Jakarta, Indonesia, 1993)	Hydrant (0,1)	**	39.1%	-	-
Asabere (2004)	Homeowners (Accra, Ghana, 1990-2000)	Lot has water and electricity connections (0,1)	**	13.9%	54	-
Knight, Herrin & Balihuta (2004)	General dwellers (Uganda, 2000)	Piped water in dwelling (0,1)	**	43.9%	8	-
Yusuf & Koundouri (2005)	Urban homeowners (Indonesia, 1997)	Piped water (0,1)	**	28.1%	312	34.1%
Yusuf & Koundouri (2005)	Rural homeowners (Indonesia, 1997)	Piped water (0,1)	NS	15.3%	34	18.9%
Harapap & Hartono (2007)	Urban renters (Indonesia, 2000)	Piped water or pumped water (0,1)	**	9.1%	17	2.0%
Harapap & Hartono (2007)	Rural renters (Indonesia, 2000)	Piped water or pumped water (0,1)	NS	0.3%	0.3	0.0%
Gulyani & Talukdar (2008)	Low-income renters in slums (Nairobi, Kenya, 2004)	Piped water (0,1)	**	9.2%	5	0.7%
Berger, Blomquist, & Peter (2008)	Homeowners (Russia, 2000)	Central water supply (0,1)	**	35.5%	216	13.2%
Lall & Lundberg (2008)	General dwellers (Pune, India, 2002)	Municipal piped water (0,1)	**	13.8%	21	1.9%
Nauges, Strand & Walker (2008)	Renters and squatters (El Salvador, 1996-1997)	No piped water (0,1)	*	42.8%	145	3.5%
Nauges, Strand & Walker (2008)	Low-income renters and squatters in slums (Guatemala, 1996-1997)	No piped water (0,1)	**	21.8%	43	1.8%
Takeuchi, Cropper, & Bento (2008)	Renters, owners, and squatters (Mumbai, India, 2003-2004)	Water in house (0,1)	**	5.1%	28	2.6%

Anselin, Lozano-Gracia, Deichmann & Lall (2008)	General dwellers (Bangalore, India, 2001)	Days per week water is available through direct connection	**	3.8%	15.7	-
Anselin, Lozano-Gracia, Deichmann & Lall (2008)	General dwellers (Bhopal, India, 2003)	Days per week water is available through direct connection	**	3.2%	6.3	-
Yusuf & Resosudarmo (2009)	General dwellers (Jakarta, Indonesia, 1997-1998)	Water source is inside (0,1)	**	103.0%	607	-
Espinoza, Balaguer & Camilla (2009)	Low-income renters (Antofagsta, Chile, 2006)	Dwelling has drinking water supply (0,1)	NS	57.7%	105	3.6%
Espinoza, Balaguer & Camilla (2009)	Low-income renters (Valparaiso, Chile, 2006)	Dwelling has drinking water supply (0,1)	**	14.0%	21	1.0%
Espinoza, Balaguer & Camilla (2009)	Low-income renters (Santiago, Chile, 2006)	Dwelling has drinking water supply (0,1)	*	56.7%	74	2.8%
Espinoza, Balaguer & Camilla (2009)	Low-income renters (Concepcion, Chile, 2006)	Dwelling has drinking water supply (0,1)	**	12.7%	23	1.1%
Bello & Moruf (2010)	General dwellers (Lagos, Nigeria, 2006)	Availability of water (0,1)	**	0.6%	3	-
van den Berg & Nauges (2012)	Homeowners (Sri Lanka, 2003-2004)	Access to private piped water connection (0,1)	**	16.4%	46	5.3%
Gulyani, Bassett, & Talukdar (2012)	Renters in slums (Nairobi, Kenya, 2004)	Access to piped water (in house or yard tap) (0,1)	**	5.8%	3	0.6%
Gulyani, Bassett, & Talukdar (2012)	Homeowners in slums (Nairobi, Kenya, 2004)	Access to piped water (in house or yard tap) (0,1)	**	118.0%	270	36.4%
Gulyani, Bassett, & Talukdar (2012)	Renters in slums (Dakar, Senegal, 2004)	Access to piped water (in house or yard tap) (0,1)	NS	6.0%	6	1.0%
Gulyani, Bassett, & Talukdar (2012)	Homeowners in slums (Dakar, Senegal, 2004)	Access to piped water (in house or yard tap) (0,1)	NS	19.5%	122	16.3%
Vasquez (2013)	Renters (Guatemala, 2006)	House has municipal piped water connection (0,1)	**	60.0%	98	-
Brueckner (2013)	General dwellers (Indonesia, 1993)	Water source outside dwelling (0,1)	**	15.5%	18	2.6%
Choumert, Stage & Uwera (2014)	Renters (Kigali, Rwanda, 2011)	Water only (no electricity) (0,1)	**	96.8%	170	23.9%
Ahmad (2015)	Homeowners (Bangladesh, 2010)	Access to drinking water from any sources maintained by statutory bodies and NGOs (0,1)	NS	-7.7%	-0.4	-0.1%
Ahmad (2015)	Renters (Bangladesh, 2010)	Access to drinking water from any sources maintained by the statutory bodies and NGOs (0,1)	**	-35.3%	-1.3	-0.2%

Ahmad (2015)	Squatters in slums (Bangladesh, 2010)	Access to drinking water from any sources maintained by the statutory bodies and NGOs (0,1)	*	257.9%	2	0.7%
Choumert, Kere & Lare-Dondarini (2016)	Homeowners (Dapaong, Togo, 2010)	Water and electricity (0,1)	**	47.0%	96	27.7%
Suparman, Folmer & Oud (2016)	Urban homeowners (Indonesia, 1993-2007)	In-house piped water connection (0,1)	**	34.2%	6	5.1%
Suparman, Folmer & Oud (2016)	Rural homeowners (Indonesia, 1993-2007)	In-house piped water connection (0,1)	**	34.2%	3	3.8%
Simiyu, Swilling, Rheingans & Cairncross (2017)	Renters in slums (Kisumu, Kenya, 2014)	Nearby water point (0,1), with "compound connection" as the base case	NS	2.0%	0.6	0.2%
Nakamura (2017)	Renters and owners in slums (Pune, India, 2013)	Exclusive water supply (0,1)	*	23.2%	55	8.1%
Amoah & Moffatt (2017)	Renters (Accra, Ghana, 2014)	Access to reliable piped water in residence (0,1)	**	32.4%	30	7.0%

[1]Market premium is presented for having the amenity. It is converted when the author uses the lack of the amenity as the variable of interest.
*Statistically significant at 0.1
**Statistically significant at 0.05

We identified and selected a set of 36 primary studies for inclusion in the analysis, listed in Table 2. Our objective was to identify papers that used the hedonic method to estimate the value of piped water supply services in a developing country context. We searched for studies using the internet (Google Scholar), the university library, and academic databases: Web of Science, JSTOR, SCOPUS, and ScienceDirect. We used key words such as "hedonic valuation" and "housing market." We did not limit our search to papers only focusing on water services as this sample is very limited (N=13). Instead, we expanded our search to include studies that include water services in their hedonic price function but do not focus on specifically water services. We limited the search to studies conducted in developing countries as defined by the International Monetary Fund (IMF, 2018). Following established protocol, we also used reference lists in identified studies to find additional papers.

From these studies, we constructed a database of estimated hedonic market premiums as well as corresponding explanatory information about both the study and the sample. Table 2 presents the studies used in this meta-analysis. It also reports the number of market premium, or marginal willingness to pay, estimates gathered from each study. Each observation corresponds to one estimate of a market premium. If a study reports numerous values, then several data points are collected (Woodward and Wui, 2001). Following Van Houtven et al. (2017), multiple estimates from a single study were only included if they were based on distinct, non-overlapping subsamples of households. Otherwise, multiple estimates were either dropped or averaged into one estimate. Explanatory variables follow the framework in Figure 1. Note that due to the limitations described earlier, we have a minimal number of variables describing household characteristics, attributes of water supply, and housing market characteristics. Explanatory variables related to research design and methods are naturally more easily collected and include study characteristics such as research design, sample size, model specification, econometric methods, and other quality variables such as having a research focus on water and date of publication (Nelson and Kennedy, 2009).

6.4 Meta-Regression Model

We would like to be able to explain the variation in market premium estimates and the extent to which it is related to observable factors discussed in our framework (Figure 1). We focus on two empirical outcomes. First, we would like to understand under which conditions there is a statistically significant relationship between piped water services and home value. Second, we examine the magnitude of the market premium as a proportion of monthly rent. This is often a direct interpretation of the coefficient derived from the model.

We explain the heterogeneity in market premium significance and magnitude using systematically collected study and sample characteristics. Using our framework, we hypothesize that the market premium depends on four types of measurable factors: household preferences; attributes of water supply; housing market characteristics; and research design and methodology:

$$marketpremium_i = f(\text{household preferences, water supply attributes,}$$
$$\text{housing market characteristics, research design \& methods})$$

In the following subsections, we describe the measurement of the dependent and independent variables used in the meta-regression model (Tables 3 and 4).

Table 6.3. Variable descriptions and summary statistics

Variable	Description	N	Mean	SD	Min	P25	P50	P75	Max
significant10	=1 if coefficient on water supply service in the hedonic model is significant at the 10% level	75	0.63	0.49	0	0	1	1	1
significant5	=1 if coefficient on water supply service in the hedonic model is significant at the 5% level	56	0.64	0.48	0	0	1	1	1
mpremium	Average market premium for water supply services as a percentage of home value, with non-significant market premiums assumed to be zero	75	0.41	0.68	-0.64	0.05	0.22	0.50	3.53
mpremium_month	Average monthly market premium for water supply services, in 2017 PPP USD	69	88	176	-39	3	23	96	938
monthly_hh_income	Average monthly household income, in 2017 PPP USD	60	912	751	65	498	727	1024	4125
monthly_home_value	Average monthly home value, in 2017 PPP USD	69	254	504	1	52	169	236	4028
missing	=1 if either income or home value is missing	75	0.24	0.43	0	0	0	0	1
Asia	=1 if the country is in Asia	75	0.61	0.49	0	0	1	1	1
owners	=1 if study sample is owners only	75	0.35	0.48	0	0	0	1	1
squatters	=1 if study sample is squatters only	75	0.13	0.34	0	0	0	0	1
prop_pw	Proportion of sample with piped water access	75	0.52	0.33	0.00	0.26	0.53	0.85	0.98
prop_pw_sq	Square of proportion of sample with piped water access	75	0.38	0.34	0.00	0.07	0.28	0.73	0.96
n_other_water_var	Number of other water supply variables included in hedonic model	75	1.20	2.02	0	0	0	2	11
tenure_insecurity	=1 if study sample consisted of tenure insecure residents	75	0.28	0.45	0	0	0	1	1
waterfocus	=1 if study focuses on water supply services	75	0.36	0.48	0	0	0	1	1
discrete_choice	=1 if researchers use a discrete choice framework to estimate the bid-rent function	75	0.28	0.45	0	0	0	1	1
semilog	=1 if the model functional form is semi-log	75	0.57	0.50	0	0	1	1	1
n_sanitation_var	Number of sanitation variables included in hedonic model	75	1.39	0.96	0	1	1	2	5
n_other_infra_var	Number of other infrastructure variables included in hedonic model	75	1.44	1.07	0	1	1	2	5
length_of_tenure	=1 if length of tenure is included in hedonic model	75	0.36	0.48	0	0	0	1	1
endo_nostrat	=1 if researchers do not account for endogeneity in their study design/methods	75	0.80	0.40	0	1	1	1	1
samplesize	Sample size, in thousands	75	1.02	1.31	0.06	0.09	0.54	1.41	5.91
wvar_PW	=1 if water supply service measured in study is "piped water"	75	0.79	0.41	0	1	1	1	1
value_sale	=1 if home value is recorded as the sale value	75	0.19	0.39	0	0	0	0	1
value_implicit	=1 if home value is imputed rent using sale value	75	0.11	0.31	0	0	0	0	1

6.4.1 Market Premiums for Water Supply Services

To obtain comparable measurements of market premiums across different hedonic methods and hedonic price functional forms, we standardize measures. First, for semi-log hedonic price functions, we used the coefficient on the water service variable. The percent change in home value is $\left(e^{\hat{\beta}} - 1\right) \times 100$. Inference using the Box-Cox coefficients can only be approximated when using the regression output. We evaluate the percent change in home value at the mean value, with change in home value, $\Delta y = \left(\hat{\lambda}(\hat{\beta}) + 1\right)^{1/\hat{\lambda}}$. Despite being standard practice, the error disturbance is not accounted for in making this conditional predication (Abreyava, 2002). We are unable to improve upon the standard practice because we do not have information about the distribution of the error term. For studies that use bid-rent or discrete choice models, we report author estimates of market premiums as a percent of home value.

6.4.2 Household Preferences

We approximate for household preferences using observable household characteristics and research context. We include two measures that were available across most studies: the home value and average household income. We also include regional fixed effects, which capture any context specific preferences, as well as variables for if the sample consists of squatters, renters, or owners. While we would have also liked to include additional measures such as education and household size, these were not widely available across studies.

We standardize the measurement of home value across studies for comparability. First, we convert all home values (rent and home sale price) to a monthly figure. As a result, we keep monthly rent as it is presented in the paper. For annual rent, we divide by twelve to obtain monthly rent. To calculate the equivalent monthly value of home price, we follow van den Berg and Nauges (2012) and treat the home price as a perpetuity, with the present value being the stated home price. We calculate the equivalent monthly rent using the present value formula, assuming a real discount rate of 10%. For the remainder of the paper, "home value" refers to this standardized measure –

with rents and sale prices pooled for comparison. Standardization does not affect market premiums as a percent of home value. The measurement and treatment of home value in the HPVM is discussed further in the “research methods and design” subsection.

We include a measure for household income – the reported monthly average household income for each study. We provide average monthly household income for subsamples where available; otherwise, we use the average figure for the entire sample. We include a dummy variable for missing household income.

Estimates of home value and household income are converted to current 2017 USD values corrected using purchasing power parity (PPP) exchange rates published annually in the World Development Report and available in the World Bank database. For studies conducted prior to 1990 for which PPP exchange rates are unavailable, predicted PPP exchange rates are used.

6.4.3 (Perceived) Attributes of Water Supply

In our framework, we identify three major groups of attributes of water supply: characteristics such as access, reliability, and water quality; costs and benefits of having piped water; and the substitutes and complements available. However, the studies focusing on water supply did not systematically report most of these attributes. Rarely do hedonic studies that focused on topics other than water supply report any of the attributes of water supply. For example, the price of piped water service delivery (water tariffs and connection fees) and how renters pay their water bills (if it is included in their rent) are not well documented in the hedonic studies. As a result, our meta-analysis is limited in its ability to understand how changing attributes of water supply can change the hedonic premium captured in the housing market.

We are able to include two measures that partially describe the attributes of piped water supply: access to piped water service and number of other water-related variables included in the hedonic model. First, we include the proportion of the sample with piped water access (*prop_pw*, *prop_pw_sq*).[27] While we would like to understand how access affects hedonic premiums, we also leverage this measure as an approximate indicator for intermittency of piped water supply because "utilities that are able to supply a higher percentage of the population within their designated service area are also better able to provide continuous supply" (Kaminsky and Kumpel, 2018). In addition, we include measures for access for two methodological reasons. First, the market premium depends on the level of service when the hedonic price function is nonlinear (Freeman et al., 2014). Second, we include the square term because we would like to account for any selection effects that occur when access is extremely low or high.

We also include a count of other water-related variables included in the hedonic model (*n_other_water_var*). Water-related variables include other sources of water, such as private wells, public wells, neighbor's water, and other infrastructure related to water use – such as storage tanks and number of bathrooms. This variable is able to partially account for the availability of substitutes and complements.

6.4.4 Housing Market Characteristics

We would like to be able to account for differences in hedonic premiums driven by differences in certain housing market characteristics, such as market activity and mobility, competitiveness, and if the market is in equilibrium. We are only able to collect one measure related to market activity and mobility: tenure security (if the sample is a squatter or slum community). We expect that those who live in squatter or slum communities experience more tenure insecurity. As a result, there may an undersupply of piped water connections due to a reluctance to invest in new connections because of the risk of eviction; the undersupply could therefore lead to higher premiums for existing piped water connections. This measure is slightly

[27] For studies that did not provide this figure, we used other sources, listed here: Rio de Janeiro in 1983 (88.4%) (Britto, 2019); Accra, Ghana in 1979 (85%) (World Bank, 1994); Manila in 1983 (53%) (World Bank, 1978); Davao in 1979 (35%) (Tabbada, 1983).

different from the one described previously under household characteristics. We focus here on those who live in slums, which could include renters and owners, not just squatters. There is another related measure, which is an indicator variable for if the length of tenure is included in the hedonic model, but we discuss this in the research design and methods subsection.

6.4.5 Research Design and Methods

The most easily observed measures come from researchers' choice of research design and methods. As a result, most of the independent variables we use in our meta-analysis fall in this subsection. We include two variables that capture research design choices: if the authors of the study focus on water supply services as its main research question (*waterfocus*) and if the authors use a discrete choice framework to estimate the bid-rent function (*discrete_choice*). We include a metric for researcher focus on water supply for two reasons. First, water researchers (and donors) can select locations where water supply is a serious problem and market premiums therefore may be higher. For example, Crane, Daniere, and Harwood (1997) state that their "sample was collected exclusively in west and north Jakarta where water availability is an especially severe problem." Second, there may be an "expectation bias" introduced by researchers who expect to find a significant effect of water services on home values. We also include an indicator variable for studies that use a discrete choice framework. Though the discrete choice model imposes more structure on the preference function than the hedonic model, two frameworks "perform equally well in estimating the marginal value of an attribute" (Cropper et al., 1993).

The measures for the research methods fall into two groups: (1) procedures that target accuracy by mitigating issues of endogeneity (Kuminoff et al., 2010) and (2) measurement procedures that affect the precision of the study. With respect to issues of endogeneity, we first examine how studies handle omitted variable bias. We include an indicator variable (*semilog*) for the choice of a semi-log functional form over linear, double log and Box-Cox functional forms. Careful selection of functional form can generate results robust to omitted variable bias. We include three other variables to directly account for omitted variable bias in these studies: the number of sanitation-related variables present in the hedonic model (*n_sanitation_var*), the number of other infrastructure-related variables present in the hedonic model (*n_other_infra_var*, such as electricity, telecommunications, or road access), and the inclusion of the number of years the resident has lived in their home (*length_of_tenure*). The length of tenure is important to capture in studies where home values are self-reported, because both "the bias and the lack of precision in homeowners' estimates are correlated with tenure, but not with socioeconomic characteristics" (Gonzalez-Navarro & Quintana-Domeque, 2009).[28] We also create an indicator variable (*endo_nostrat*) for if the authors do not employ techniques to address more complex forms of endogeneity, such as simultaneity, (spatial) autocorrelation, and selection bias. The indicator variable is equal to zero if these techniques are used and equal to one if the first stage hedonic price function is simply estimated without any techniques to address any of the forms of endogeneity discussed above.

We then look at four areas of measurement that may affect the precision of the study. First, we include the sample size in thousands (*samplesize*). Variation in sample size may affect the significance of the estimates (Braden et al., 2011). Second, we include an indicator variable for how water services are measured in the hedonic study, with *wvar_PW* equal to one if the water service variable of interest in the study is a simple indicator variable for "access to" or "presence of" piped water in the home. The variable is equal to zero otherwise. Third, we include the how the home

[28] The measurement of home value is a common challenge faced by all hedonic modelers, and self-reported measures have been found to lead to consistent results and can be comparable to results using sales price data. There is literature in both high-income and low-income countries that describes the differences between self-reported and sales price data. In both contexts, owners tend to overestimate the value of their house. But the error in owner's estimates is not highly correlated with home or owner characteristics. Results are broadly consistent between those based on self-reported values and those based on actual transactions (Goodman & Ittner, 1992; Freeman, 1979; Kain & Quigley, 1972; Gonzalez-Navarro & Quintana-Domeque, 2009; Jimenez, 1982). While Jimenez (1982) and Gonzalez-Navarro and Quintana-Domeque (2009) find a larger difference in valuations for self-reported housing values (55% and 150% vs. 20% in Kain and Quigley (1972)), they find that the model results are not different. Most of the studies in our meta-analysis rely on self-reported home valuations; our results are robust to the inclusion of an indicator variable for the use of self-reported values and do not find significant coefficients.

value is measured: as a sale price, rental price, or implicit rental price derived from the estimated sale price. We include two indicator variables for sale price (*value_sale*) and implicit rental price (*value_implicit*), with rental price as the base case. It is important to understand how home values are measured and included in the model, since different measurements can be associated with distinct economic concepts. For example, market premiums as a proportion of monthly rent is a different measure from market premiums as a proportion of (estimated) sale price. The rental price represents the value of existing amenities in the current time period, rather than future changes in asset values (Taylor, 2003, Epple et al., 2013). There can also be differences in rates at which local amenities are capitalized into property prices (e.g., due to differential mobility and transactions costs), and renters and homeowners may have systematic differences in preferences related to environmental amenities (Clark & Nieves, 1996).

Fourth, we examine the composition of the study sample: if they are owners only, squatters only, renters only, or mixed. We include two indicator variables for owners only (*owners*) and squatters only (*squatters*), with the base case as renters only.

6.5 Results

6.5.1 Summary of the Hedonics of Piped Water Supply in Low and Middle Income Countries

We find 13 hedonic studies that focus on valuing water supply in developing countries. We expect these studies to provide the most thoughtful valuation estimates for piped water supply. However, we find there is a large range of market premiums within this subsection of the literature, with market premium estimates for piped water supply ranging from 0.032 to 3.53 of home value. Additionally, not all market premiums are statistically significant. Of 26 market premium estimates, 21 are statistically significant at the 10% level.[29] There are also large outliers in this subsample of

[29] The five statistically insignificant estimates for piped water connections are from rural areas (Harapap and Hartono, 2007; Yusuf and Koundouri, 2005), squatters in Bangkok (Crane et al., 1997), homeowners in Jakarta (Crane et al., 1997), and one of the four cities in Chile studied by Balaguer et al. (2009).

estimates – with two above 100% of the home value, both from Crane et al. (1997). We summarize the study findings below, drawing attention to the large range of research contexts, designs, and methods used.

Two studies find evidence suggesting that willingness to pay for a piped water connection can be low when service is intermittent and/or when "obtaining access to a piped water connection is not seen as a big improvement in terms of water safety and quality" (van den Berg and Nauges, 2012). Anselin et al. (2008)[30] report two of the smallest market premiums in this literature review, with 0.032 for Bhopal and 0.038 for Bangalore, for a piped water supply service improvement of one day per week (on average, it is a 33% improvement in service hours). Their market premium is calculated using a spatial lag model that captures both (1) a direct effect on the household and (2) a spatial multiplier effect that captures the benefits from a household's piped water access that spill over to their neighbors, which also in turn, benefit the household. Anselin et al. (2008) also control for access to other water supply sources and water storage. Van den Berg and Nauges (2012) also find a small market premium of 0.16 for homes in Southwest Sri Lanka. The authors explain that in Southwest Sri Lanka, "unconnected households are satisfied with the quality (i.e., taste, color, smell, and safety) and service of non-piped water," and that among connected households, there were "frequent complaints about piped water being available for less than 24 hours a day," which was also the case in Bhopal and Bangalore (van den Berg and Nauges, 2012).

The low market premiums found by van den Berg and Nauges (2012) and Anselin et al. (2008) are complemented by two other studies that find similarly low market premiums but use simpler research design and methods. Harapap and Hartono (2007) and Espinoza et al. (2009) report market premiums of 0.09 in urban areas of Indonesia and 0.13 and 0.14 in Concepcion and

[30] One of the highest quality studies. Their hedonic market premiums for a service improvement of one day per week (54 INR for Bhopal, 117 INR for Bangalore) are consistent with results from a willingness to pay survey conducted for the same households (45 INR for Bhopal, 119 INR for Bangalore).

Valparaiso, Chile, respectively. These two studies use simple OLS regressions to estimate the hedonic price functions, with indicator variables for the "availability of piped or pumped water" (Harapap and Hartono, 2007) or the "dwelling having a drinking water supply" (Espinoza et al., 2009). The authors do not describe the service levels provided or the availability of alternative sources and water storage.[31] Van den Berg and Nauges (2012) also reference Nauges et al. (2008), who report slightly higher market premiums for piped water connections of 0.22 in Guatemala using OLS and 0.43 in El Salvador using an instrument for the size of the lot. Nauges et al. (2008) use private piped water connections as the reference group and instead include dummy variables for having a private well (in El Salvador), access to truck services (in Guatemala), and other types of water access (i.e., public taps, public wells, someone else's tap). The authors suggest that the estimates from Guatemala may be "more trustworthy," as the sample consists entirely of marginal "barrios" and therefore have less noise (Nauges et al., 2008).

In a contrasting study, Amoah and Moffatt (2017) find higher market premiums for having "reliable piped water in residence," as we would expect. Using a log-linear model, they find a market premium of 0.32 in Accra, Ghana, equivalent to about 7% of household income (Amoah and Moffatt, 2017).[32] The authors then compare the results from two other valuation methods, finding that the hedonic WTP measure is theoretically consistent and similar to the WTP derived using the contingent valuation method (7.5% of household income) and higher than that derived using the travel cost method (3.6% of household income).

[31] We know from other studies that water services in Indonesia at the time of the study were of poor quality, had low pressure and incomplete coverage (Kooy and Bakker, 2008), but water services in urban Chile had high coverage levels and were being well-managed, with a noteworthy targeted subsidy program (Hearne and Donoso, 2005; Gómez-Lobo and Contreras, 2003).

[32] The market premium is misinterpreted in the paper, as the percentage increase is equated to the coefficient from the log-linear model. As a result, we present a corrected market premium of 0.32.

There are two studies that examine the value of piped water supply in rural areas when compared to urban areas in Indonesia; both use data from the Indonesia Family Life Survey but draw different conclusions. Yusuf and Koundouri (2005) use the Heckman selection model to investigate how the decision on house location (urban vs. rural) affects the household's valuation of piped water in Indonesia. They find a market premium of 0.28 for urban areas, or IDR 14,053 (3.6 per cent of expenditure). They do not find a significant coefficient in rural areas. Unlike Yusuf and Koundouri (2005), Suparman et al. (2016) fail to reject the hypothesis that the WTP for piped water is different in rural and urban areas. They attribute the lack of difference to two main reasons. First, that "health, […] closely related to the availability of clean and safe drinking water, is valued approximately equally in both areas," and second, because sources of safe drinking water have declined in rural areas, the availability of safe alternatives in both rural and urban areas have converged (Suparman et al., 2016). Using an autoregressive-structural equation approach to account for time-varying omitted variables and measurement error, they find a market premium of 0.34 of home value in both urban and rural areas (equivalent to 5% and 3% of total household expenditure, respectively).

Also examining piped water supply in rural areas, North and Griffin (1993) look at 1,900 rural households in the Philippines. Following Ellickson (1981), they directly estimate the bid-rent function and find that households in "all income ranges are willing to pay about half their monthly imputed rent to have piped water in the house" (North and Griffin, 1993). The authors control for access to other water sources but do not characterize the service levels provided from the piped water supply beyond "most convenient and under most conditions the safest" (North and Griffin, 1993).

There are four studies reporting large market premiums; the authors often explain their results by (1) acknowledging that dummy variables "may capture the presence of unobserved amenities" and therefore their "results should be interpreted as upper bound values" (Choumert et al., 2016) or (2) stating that their results are comparable with those from other studies (Choumert, Stage, and Uwera, 2014; Vasquez, 2013; Crane et al., 1997). Vásquez (2013) finds a market premium of 0.60 of rental prices in urban Guatemala using a maximum simulated likelihood approach with household characteristics as instruments. Choumert et al. (2016) find a market premium of 0.47 for joint access to water and electricity in Dapoang, Togo,[33] and Choumert, Stage, and Uwera (2014) find a market premium of 0.97 in Kigali, Rwanda. Both studies correct for issues of spatial autocorrelation, but neither address other endogeneity issues such as potential reverse causality or other key omitted variables. Finally, Crane, Daniere, and Harwood (1997) conduct a comparative study of piped water supply in slums in Jakarta and Bangkok. They find the largest hedonic market premiums – 3.53 times the value of the home for renters and 1.36 times the value of the home for owners in Bangkok.[34] The authors acknowledge that these values are "relatively high, [… but still…] comparable to values noted in other studies," citing North and Griffin's (1993) market premium of around half of monthly rent (Crane et al., 1997). Offering no other explanation for the large market premiums found, Crane et al.'s (1997) findings that households are willing to pay over 50% of their monthly household income for piped water services are difficult to believe.

6.5.2 Market Premiums for Piped Water Supply Services

After expanding the pool of studies to include those that do not focus solely on water supply, we derive 70 market premiums for piped water supply services from the total of 34 studies. We examine both significance and magnitude, as a proportion of home value. Of the 70 market

[33] An earlier version of their study (Choumert et al., 2014) had a hedonic price function that included "access to piped water within the dwelling" as a separate indicator variable. However, they found that the coefficients on piped water and electricity access, separately, were not statistically significant in their preferred specification (log-linear model), but their discussion section was clearly making a case for the importance of water and sanitation services.

[34] They do not find statistically significant relationships between piped water supply and home values for squatters in Bangkok and owners in Jakarta; the magnitudes of the non-significant coefficients are 0.59 and 0.82, respectively, and are still higher than most other market premiums.

premiums, 44 are significant at the 10% level. Not all of the papers report significance at the 5% level. Of the 51 estimates testing for significance at the 5% level, 33 are significant.

Figure 6.2. Hedonic market premiums (proportion of home value), by significance

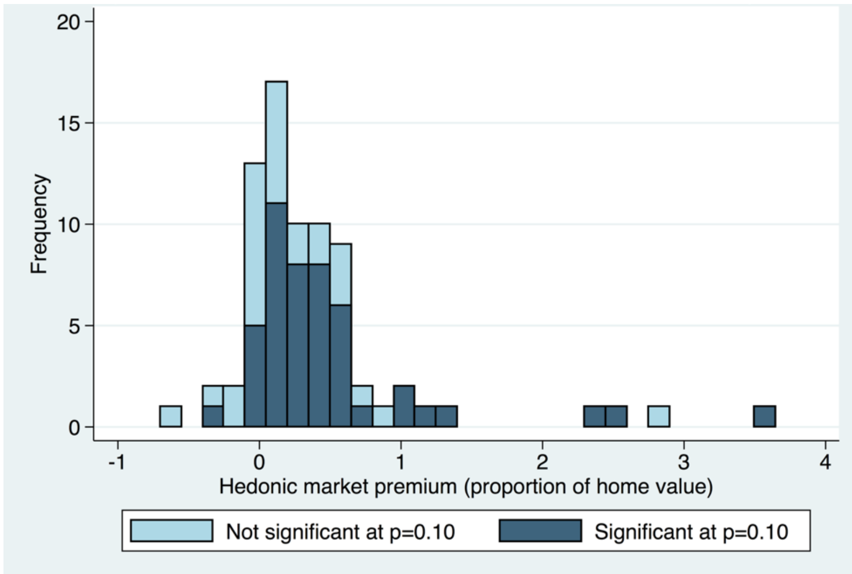


Figure 2 shows the meta-sample distributions for market premium magnitudes (that are significant at the 10% level). The distribution of significant market premiums has a sample mean of 0.53, a median of 0.34, and a standard deviation of 0.73. The minimum and maximum values in the sample are -0.35 and 3.53, respectively. Most of the market premiums fall below 0.50, or 50%, of home values. We have a few outliers, namely one negative market premium for renters in Bangladesh (Ahmad, 2015) and six that are greater than 1.00, or 100%, of home values. Extremely large market premiums of 353% are reported for renters in Bangkok (Crane et al., 1997), 258% for squatters in Bangladesh (Ahmad, 2015), 238% for high-middle income squatters of household sizes less than seven in Manila, Philippines (Daniere, 1994).[35]

[35] We do not exclude these measures as outliers in the meta-regression because it is important to be able to explain their occurrence, especially since these large market premiums are not noted to be especially large by the authors of the studies.

6.5.3 Household Preferences as Shaped by Household Characteristics and Research Context

We find that the mean monthly home value is US$220 PPP/month, with a standard deviation of US$294 PPP. The median monthly home value is US$169 PPP/month. There is one outlier value of US$2,055 PPP/month, from single family homes in Jos, Nigeria (Megbolugbe, 1989). We do not attribute this large value to measurement error and thus do not exclude it in our analysis.[36] Larger market premiums are associated with smaller home values, suggesting that household willingness to pay for piped water services may be more of a fixed value than a relative value.

The average household income is US$912 PPP/month, with a standard deviation of US$751 PPP and median of US$727 PPP/month. Out of 75 observations, 15 are missing average household income. As we would expect, there is a small, positive correlation between market premiums and monthly household income.

Hedonic studies have been conducted in many different countries and with samples consisting of homeowners, renters, and those who have less tenure security, as squatters or those living in slums. Most of the market premiums come from Asia (N=46) – with most from the Philippines (N=24), Indonesia (N=10), and India (N=5). There are 10 market premiums from Latin and South America, and 17 market premiums measured in Africa. There is also one study looking at housing in Russia (Berger et al., 2008).

Most of the market premiums are estimated for owner-only samples (N=26) and renter-only samples (N=23). There are ten squatter-only sample estimates of market premiums for piped water services and the rest consist of mixed samples (N=16). Market premiums for different tenure groups are generally similar and have large ranges for market premiums. Mixed samples report slightly lower market premiums (as a proportion of home value). The market premiums for renter-

[36] At the time of the study (1982), one Nigerian naira (NGN) was valued at 1.4 USD and has since fallen, with an exchange rate of 306 NGN for one USD in 2017.

only samples range from -35% to 353% and average 38%, or US$72 PPP/month. For homeowner-only samples, the market premiums range from -23% to 136%, averaging 35% or US$115 PPP/month. Squatter-only samples report market premiums ranging from -64% to 280%, averaging 89% or US$45 PPP/month. Mixed samples have mean market premiums of 25% of home value (US$92 PPP/month), ranging from 0% to 103%.

6.5.4 (Perceived) Attributes of Piped Water Supply

We find that there is a wide range of access levels across study contexts. With respect to the proportion of households with piped water connections, the average across all estimates is 0.50. Out of 67 samples with levels of access to piped water connections, 14 samples report proportions of less than 0.20, and 21 report proportions of 0.80 or higher.

Thirty-three out of 75 hedonic models include other water-related variables. The average number of other water-related variables is 2.7, with a standard deviation of 2.3.

6.5.5 Housing Market Characteristics

Of the 75 market premiums, 21 come from households that experience tenure insecurity – living in slums or squatter communities. Ten of the 21 samples are squatter-only samples, five are renter-only, three are owner-only, and three are mixed samples. We find that the mean market premium is significantly larger for households experiencing tenure insecurity (mean=0.77, SD=1.13) than for those that do not (mean=0.27, SD=0.28).

6.5.6 Research Design and Methods

Of the 75 market premiums estimated, 36% of them come from studies that focus on piped water supply services. Of the 27 estimates that come from studies focusing on water, 22 are significant. In comparison, of the 48 estimates that comes from studies that do not focus on water, 23 do not find a statistically significant effect of piped water services on home values. Twenty-one of the hedonic market premiums are estimated using a discrete choice framework.

Omitted variable bias can be addressed using different functional forms and by including pertinent variables. We find that semi-log models tend to be the most commonly used, with 57% of the market premiums estimated using this functional form. Most hedonic models (84%) include other sanitation-related variables, with an average of 1.39 variables. Other infrastructure-related variables are also commonly included (85%), averaging 1.44 variables. Most hedonic models do not, however, include the household's length of tenure (36%).

In the papers published between 1981 and 1996, authors did not address the more difficult endogeneity problems of the independent variables in the estimation of the first stage hedonic price function. Later studies employed various techniques to address different forms of endogeneity (simultaneity, (spatial) autocorrelation, selection bias). Crane et al. (1997), Nauges et al. (2008), Vásquez (2013), Choumert et al. (2016), and Nakamura (2017) all used instrumental variable techniques to address endogeneity concerns. Anselin et al. (2008) and Asabere (2004) used estimators that correct for spatial autocorrelation. Suparman et al. (2016) used a structural equation approach to reduce omitted variable bias and to correct for endogeneity of the presence of a piped water connection. Yusuf and Koundouri (2005) used a selection correction for location choice (urban vs. rural), and Brueckner (2013) and Berger et al. (2008) corrected for reporting bias. As a result, we have 15 market premium estimates from studies utilizing more sophisticated techniques.

We also find that most papers do not move beyond estimating the first stage's hedonic price function, which only provides the market premium for an amenity. The problem of identification in estimating the second stage is well known (Taylor, 2008; Nakamura, 2017). Papers that focus on water do not attempt Rosen's (1974) second stage estimations. Two other papers do, but they do not focus on water (Arimah, 1992; Quigley, 1982). Two papers of these use Bajari and Kahn's (2005) three-stage approach (Lall & Lundberg, 2008; Nakamura, 2017).

With respect to areas of measurement that may affect study precision, we examine sample size, measurement of piped water services, measurement of home value, and composition of study sample. First, with respect to sample size, we find that studies range from a minimum of 57 observations to a maximum of 5,910 observations. Market premiums that are statistically significant at the 10% level are estimated using samples averaging 1,322 observations, while those that are not average 525 observations. Second, the measurement of water services is commonly simplistic, with authors using an indicator variable for "access to" or "presence of" piped water in the home for 79% of hedonic models. Third, we find that while most (63%) models use rental price as the measure for home value, 19% use home sale price, 11% use implicit rental price (derived from home sale price). The composition of the study sample is discussed previously as a household characteristic.

A majority of market premiums are estimated in urban areas (N=68), with three that are estimated for the entire country (Knight et al., 2004; Brueckner, 2013; Suparman et al., 2016). With respect to study age, the oldest study had data collected in 1976. The longest intervals are 32 years (1947-1978) (Asabere, 1981), 15 years (1993-2007) (Suparman et al, 2016), and 11 years (1990-2000) (Asabere, 2004). All other studies are cross-sectional, with data collected in one or two years.

6.5.7 Significance of Piped Water Supply Services

Table 4 reports the results of the probit model for a statistically significant coefficient on piped water supply services in the hedonic model. The first specification for the explanatory model looks only at variables related to household characteristics: household income, home value, region, and tenure status. Estimation of model (1) shows that home value and squatters have statistically significant, negative coefficients. More valuable homes are less likely to find a significant effect of piped water supply services on home value. Squatters are also less likely to find a significant effect.

The second specification adds covariates related to piped water supply attributes: the proportion of the study sample with access to piped water, its square term, and the number of other water variables included in the model. None of the coefficients on these covariates are statistically significant. The coefficient on *squatters* remains statistically significant at the 1% level, but the coefficient on home value loses its significance at the 10% level. The addition of the covariates related to piped water supply does not change the sign of coefficients on other variables.

Model (3) includes one additional variable on tenure security, a housing market characteristic. While the coefficient on this variable is not statistically significant, its addition leads to a loss of statistical significance for *squatters*, and *owners* now has a statistically significant coefficient at the 10% level.

Model (4) adds variables related to research design and methods: a study's focus on piped water (*water_focus*) and the use of the discrete choice framework (*discrete_choice*). Models (5) and (6) examining the effects of research method variables related to accuracy and precision, respectively: choice of functional form of the hedonic price function (*semilog*); number of variables included in the model related to sanitation (*n_sanitation_var*), other infrastructure (*n_other_infra_var*), and length of tenure (*length_of_tenure*); not addressing other forms of endogeneity (*endogeneity*); sample size (*samplesize*); use of an indicator variable for piped water supply (*water_dummy*); and type of home value measured (*value_sale*, *value_implicit*, with *value_rent* as the reference category). The coefficient on *water_focus* is statistically significant and positive through the remaining models (5 and 6). While the coefficient on *discrete_choice* is not statistically significant in model (4), it becomes statistically significant at the 5% level in models (5) and (6), with the addition of other methodological variables. Models (5) and (6) have similar reports with respect to coefficient sign and significance. We find that the coefficient on the number of variables included in the model related to other infrastructure is positive and significant at the 5% level. Hedonic models that include other infrastructure access are more likely to report a significant coefficient on piped water supply services. The coefficient on *endogeneity* is significant at the 1% level and negative. Studies that do not address more complex forms of endogeneity are less likely to find statistically significant hedonic premiums for piped water supply. The form of the water supply variable also matters: models that simply use an indicator variable for the presence of a piped water connection are more likely to find a statistically significant hedonic market premium.

Table 6.4. Meta-analysis results explaining significance of water supply services

VARIABLES	(1) *significant10*	(2) *significant10*	(3) *significant10*	(4) *significant10*	(5) *significant10*	(6) *significant10*
ln_monthly_hh_income	0.25	0.32	0.30	0.27	0.82***	0.97**
	(0.23)	(0.25)	(0.25)	(0.23)	(0.32)	(0.41)
ln_monthly_home_value	-0.19*	-0.13	-0.12	-0.23*	-0.98**	-1.11**
	(0.11)	(0.12)	(0.12)	(0.13)	(0.40)	(0.49)
missing	0.50	0.39	0.22	0.73	2.69***	3.31***
	(0.39)	(0.45)	(0.43)	(0.54)	(0.80)	(0.93)
Asia	-0.029	-0.28	-0.40	-0.58	-1.23**	-1.28**
	(0.32)	(0.38)	(0.40)	(0.48)	(0.51)	(0.60)
owners	-0.53	-0.58	-0.61*	-0.57	-0.41	-1.13
	(0.38)	(0.35)	(0.33)	(0.36)	(0.36)	(0.73)
squatters	-1.25***	-1.32***	-1.00	-1.41*	-2.21**	-2.77***
	(0.41)	(0.46)	(0.66)	(0.77)	(0.99)	(0.97)
prop_pw		0.014	0.51	2.62	8.22*	9.63
		(2.83)	(2.91)	(2.82)	(4.83)	(6.58)
prop_pw_sq		-0.99	-1.49	-3.33	-7.67*	-9.08*
		(2.51)	(2.63)	(2.54)	(3.96)	(5.44)
n_other_water_var		0.092	0.12	0.051	-0.16	-0.099
		(0.085)	(0.091)	(0.14)	(0.18)	(0.19)
tenure_insecurity			-0.40	0.055	1.12	0.78
			(0.48)	(0.54)	(0.86)	(1.04)
waterfocus				1.03**	2.68***	3.03***
				(0.49)	(0.92)	(1.01)
discrete_choice				0.56	2.21**	2.45**
				(0.52)	(1.04)	(1.02)
semilog					-0.51	-0.86
					(0.58)	(0.68)
n_sanitation_var					0.19	0.062
					(0.32)	(0.22)
n_other_infra_var					0.49**	0.61**
					(0.24)	(0.30)
length_of_tenure					-0.32	0.11
					(0.55)	(0.68)
endo_nostrat					-3.71***	-4.32***
					(1.17)	(1.21)
samplesize						0.0072
						(0.23)
wvar_PW						1.20*
						(0.67)
value_sale						1.08
						(0.70)
value_implicit						-0.20
						(0.76)
Constant	-0.12	-0.38	-0.20	-0.41	-0.045	-1.04
	(1.53)	(1.68)	(1.67)	(1.48)	(2.13)	(2.48)
Observations	75	75	75	75	75	75
Pseudo-R^2	0.1121	0.1581	0.1640	0.2089	0.3698	0.4052

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The addition of these variables related to research design and methods changes the statistical significance of other variables. Coefficients on household income, home value, region, squatters, and the square term of the proportion of the study sample with access to piped water all become statistically significant. We find that samples with higher levels of income are more likely have report a significant coefficient on piped water services. However, all else equal, samples with more valuable homes are less likely to report a significant hedonic market premium for piped water services. Additionally, studies in Asia are less likely to find significant relationships between home value and water services; squatters continue to be less likely to have a significant market premium. Interestingly, the coefficient on the square term for access to piped water is statistically significant at the 10% level and negative. This suggests that for low levels of access, the relationship between home value and piped water services is more likely to be significant, but for higher levels of piped water access, the relationship is less likely to be statistically significant.

Our results indicate robust effects of having a study focus on piped water supply services, squatters, and not having a strategy to handle endogeneity on a statistically significant coefficient on piped water supply services. With respect to other study characteristics, we are unable to find a strong relationship with statistical significance of the coefficient on piped water supply services. Household and piped water supply attributes are weak explanatory variables for market premium significance without the presence of research method and design explanatory variables.

6.5.8 Piped Water Supply Service Market Premiums

Table 5 presents the results of the meta-analysis regression explaining the magnitude of market premiums (*mpremium*). As in the probit model for statistical significance, the first specification for the explanatory model looks household characteristics. Estimation of model (1) shows that none of the variables related to household characteristics are statistically significant and have weak explanatory power ($R^2 = 0.085$). In model (2), we add covariates describing the attributes of water supply. The coefficients on access to piped water supply in the sample (*prop_pw*) and its square term (*prop_pw_sq*) are statistically significant at the 5% level. The coefficients are negative and positive, respectively, suggesting a U-shaped relationship centered at 0.5 between access to piped water supply and hedonic market premiums. Market premiums (as a percentage of home value) are higher when water access is low or high. The addition of covariates in model (2) changes the significance of *squatters*, which now has a positive relationship with market premiums; the sign of the coefficient on *owners* is now negative, but still not significant. The signs and significance of the other coefficients remain unchanged. Explanatory power of model (2) (R^2 = 0.136) is improved compared to that of model (1). Model (3) adds tenure security, which is not significant, but the explanatory power increases substantially to 0.195. The coefficient on *squatters* loses its statistical significance.

As in the probit regressions, models (4), (5), and (6) add variables related to research design and methods, accuracy, and precision. We find that having a study focus on water services has a positive and significant relationship with hedonic market premium magnitudes. This effect is robust across all three specifications. The number of variables related to other infrastructure is positive and significant at the 5% level in model (6). The addition of research design and method variables causes the coefficient on the number of other water supply variables to be negative and significant at the 10% level. Having a larger sample size is associated with smaller market premiums, significant at the 5% level. Using an indicator variable to describe piped water services is associated with larger market premiums and is also significant at the 5% level. The coefficient on the proportion of the study sample with access to piped water services remains robustly significant at the 5% level and the magnitudes also remain stable. Two variables related to household characteristics gain statistical significance but are not robustly significant across specifications: household income and the sample being located in Asia. We also find a positive income effect: higher household incomes are associated with high market premiums for piped water services.

Table 6.5. Meta-analysis results explaining magnitude of market premiums for piped water

VARIABLES	(1) *mpremium*	(2) *mpremium*	(3) *mpremium*	(4) *mpremium*	(5) *mpremium*	(6) *mpremium*
ln_monthly_hh_income	0.072	0.039	0.066	0.069	0.042	0.19**
	(0.044)	(0.052)	(0.050)	(0.058)	(0.063)	(0.083)
ln_monthly_home_value	-0.019	0.012	-0.0099	-0.029	-0.034	-0.073
	(0.051)	(0.050)	(0.038)	(0.039)	(0.041)	(0.047)
missing	0.038	-0.023	0.20	0.36**	0.34	0.63**
	(0.13)	(0.19)	(0.15)	(0.16)	(0.21)	(0.26)
Asia	0.057	0.14	0.26	0.38	0.45*	0.48**
	(0.19)	(0.18)	(0.23)	(0.23)	(0.26)	(0.22)
owners	0.018	-0.065	-0.0093	0.056	0.050	0.015
	(0.14)	(0.13)	(0.098)	(0.11)	(0.13)	(0.15)
squatters	0.54	0.60**	0.17	0.26	0.24	0.071
	(0.33)	(0.27)	(0.49)	(0.57)	(0.60)	(0.53)
prop_pw		-2.03**	-2.24**	-1.99*	-2.24**	-2.12**
		(0.92)	(1.01)	(1.00)	(1.04)	(0.97)
prop_pw_sq		2.06**	2.30**	2.16**	2.44**	2.10**
		(0.96)	(1.07)	(1.03)	(1.11)	(0.96)
n_other_water_var		0.020	-0.0026	-0.061*	-0.070*	-0.073*
		(0.043)	(0.032)	(0.034)	(0.040)	(0.037)
tenure_insecurity			0.53	0.65	0.68	0.70
			(0.40)	(0.42)	(0.47)	(0.51)
waterfocus				0.34*	0.32*	0.46**
				(0.18)	(0.17)	(0.20)
discrete_choice				-0.20	-0.032	0.18
				(0.17)	(0.20)	(0.21)
semilog					0.22	0.27
					(0.16)	(0.16)
n_sanitation_var					-0.041	0.013
					(0.063)	(0.056)
n_other_infra_var					0.058	0.14**
					(0.042)	(0.060)
length_of_tenure					-0.071	-0.36
					(0.20)	(0.31)
endo_nostrat					-0.012	-0.18
					(0.13)	(0.13)
samplesize						-0.17**
						(0.077)
wvar_PW						0.51**
						(0.20)
value_sale						-0.040
						(0.18)
value_implicit						-0.33
						(0.28)
Constant	-0.094	0.22	-0.044	-0.23	-0.20	-1.21
	(0.38)	(0.33)	(0.41)	(0.38)	(0.41)	(0.74)
Observations	75	75	75	75	75	75
R-squared	0.085	0.136	0.195	0.244	0.262	0.339

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Samples in Asia, on average, find higher market premiums. The additional variation explained by research design and methods covariates is significant, with an R^2 of 0.339 in model (6), compared to an R^2 of 0.195 in model (3).

Our meta-analysis results show that larger market premiums are related to (1) low and high proportions of homes in the sample with piped water, (2) households with higher incomes, (3) having a research focus on water supply, (4) inclusion of other infrastructure variables in the hedonic model, and (5) the measurement of piped water supply using an indicator variable.

6.6 Discussion

The meta-analysis regression and qualitative examination of the heterogeneity in hedonic market premiums illustrates common challenges in the application of the hedonic property valuation method. We find a wide range of market premiums, from –US$39 per month to US$938 per month, with an average of US$88 per month.

We find that the hedonic valuation method is broadly unreliable for two reasons. First, the standard errors of the market premium estimates are large, as indicated by the lack of statistical significance of piped water in many models; 28 of 75 hedonic models do not find a significant coefficient on piped water supply at the 10% level. Only 36 of the hedonic models estimated – less than half – find statistical significance at the 5% level. Furthermore, we find that many of the research procedures affect the statistical significance of the coefficient and therefore the magnitude of the variance. Second, as a close substitute for test-retest experiments, we find five hedonic studies that use Indonesia's IFLS survey data but have different results. Recall that Yusuf and Koundouri (2005) find a market premium of 0.28 (312 PPP 2017 USD) for urban homeowners in Indonesia, while Suparman et al. (2016) find a market premium of 0.34 (6 PPP 2017 USD) for the same sample. Their main results about the differences between urban and rural homeowners are also conflicting. Moreover, three additional studies find varying market premiums of 0.16 (18 PPP

2017 USD) (Brueckner, 2013), 0.09 (17 PPP 2017 USD) (Hartono and Harahap, 2007), and 1.03 (607 PPP 2017 USD) (Yusuf and Koundouri, 2005).

With respect to content validity, we do not find there to be agreement among researchers on the procedures and econometric approaches to be used in HPVM in estimating accurate market premiums for piped water connections. There is a lack of consensus around research design – how to deal with endogeneity (if at all), the structure of the price function, and consideration of suitable contexts. There is also a general lack of agreement around methods and the consequent interpretation of results. While most studies use an indicator variable for the presence of piped water connections, the theoretical justification and interpretation is not consistent. Additionally, inclusion of other infrastructure-related and water and sanitation variables is not consistent across all studies.

In assessing construct validity, we find that the hedonic estimates of marginal WTP for piped water connections is consistent with economic theory (Gunatilake et al., 2007). First, we are more likely to find a significant relationship between home value and having a piped water connection as household income increases. Second, controlling for home value, we find that households with higher incomes have higher market premiums for piped water connections. We are unable to test for the relationship with price as most papers do not report the existing water tariff or average water bill for household in their sample.

A second component of construct validity is to compare hedonic marginal WTP estimates with those found using stated preference methods and coping costs. This also serves to provide guidance in the literature about what a plausible and "reasonable" hedonic market premium for piped water should be. Van Houtven et al. (2017) conduct a meta-analysis of stated preference method estimates of household willingness to pay for improved water services. Drawing from 60 studies, Van Houtven et al. (2017) find that the average incremental monthly WTP for improvements[37] range in value from $0.02 to over $176, with an average value of $22 (median of $12).[38] From their meta-analysis regression, they find a significant and positive willingness to pay a price premium for access to a private connection (compared to a public source) to be an increase of 143%, or about $31.[39]

Based on previous studies, we expect findings from stated preference studies to be similar to those from hedonic studies (Cummings et al., 1986; in Amoah & Moffatt, 2017). Two studies in our review compare SP estimates to hedonic market premiums and find similar results. Amoah and Moffatt (2017) find that the value derived from the contingent valuation method is greater than that of the hedonic method ($15.25/month compared to $11.85/month, respectively); Anselin et al. (2008) find there to be "a surprising degree of consistency" between the estimates from their SP survey and the hedonic method (45 INR vs. 54 INR, respectively, in Bhopal, and 119 INR vs. 117 INR, respectively, in Bangalore). While these few studies provide a suggestion of how results from the two methods should compare, it remains unclear exactly how much larger or smaller estimates from these two methods should be. Of the statistically significant results, the mean hedonic market premium is $106, with a median of $28. The median hedonic market premium is close to the mean willingness to pay of $31 estimated by stated preference techniques, but the mean hedonic market premium is over three times as large. As a result, we find that hedonic market premiums may be accurate when compared to results from stated preference studies, but they are not precise.[40]

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[37] Improvements are from baseline conditions to service levels proposed in stated preference scenarios.

[38] Converted to 2017 PPP USD for comparability.

[39] Because the average WTP for access to a public source is not reported, we use the mean value ($21.70) reported in the study.

[40] We caveat this comparison with a recognition that we cannot exactly compare hedonic market premiums with WTP elicited from stated preference studies. Hedonic market premiums estimate uncompensated demand while stated preference methods often estimate compensated demand. However, estimates of income elasticities of household water demand are relatively small (Nauges and Whittington, 2009), so we expect the difference between Hicksian and Marshallian demand to be small.

When comparing hedonic market premiums to household expenditures spent coping with unreliable, poor quality public water supplies, we expect coping costs to be lower because "coping costs can generally be expected to represent a lower bound for WTP" (Pattanayak et al., 2005).[41] Indeed, we find coping cost estimates (adjusted to 2017 USD) from four illustrative studies to be lower than the median and mean hedonic market premiums.[42] In Kathmandu, Nepal, mean monthly coping costs are $4.06 in 2001 (Pattanayak et al., 2005) and $13 in 2014 (Gurung et al., 2017). Cook et al. (2016) find mean monthly coping costs of $22 in rural Kenya. Zérah (1998) estimates monthly coping costs to be $8.30 in New Delhi, India. Note that these figures presented are illustrative and are not meant to provide a rigorous comparison, because we have only a few measures, not a comprehensive meta-analysis.

However, it is unclear how much larger hedonic market premiums should be when compared to the lower bound illustrated by coping costs. Only one paper compares hedonic market premiums and averting expenditures for the same set of homes. Christensen et al. (2019) use difference-in-differences and event study research designs to robustly identify the impacts of a water supply crisis and estimate welfare effects using home values in Flint, Michigan. The authors find that when compared with control housing markets, average homes in Flint have a decrease of 33%, equivalent to a 50% increase, in home value (Christensen et al., 2019). The authors find hedonic estimates (a reduction of $22,200 per home) that are close to averting expenditures ($18,249 per household, including $7,249 for replacement of domestic pipes, hot water heaters, dishwashers, and washing machines) (Christensen et al., 2019). The coping costs from the four

[41] However, there have been reports of WTP being lower than coping costs due to an erosion of household confidence in the water system (Virjee and Gaskin, 2010) or investments in storage tanks that simulate continuous water supply, "resulting in indifference to proposed water service improvements" (Mycoo, 1997; Majuru et al., 2016).

[42] Chosen because they are rigorous and include water collection times; three are reviewed in Majuru et al.'s (2016) systematic review.

studies average $12/month, nearly half of the median hedonic market premium, $28/month, and about one-tenth the mean hedonic market premium, $106/month. Compared to Christensen et al.'s (2019) findings, this suggests that hedonic estimates are generally too large when compared with coping costs.

Overall, we find that the hedonic market premiums can be accurate but are not precise, as many estimates are implausibly large. The distribution of market premiums (recall Figure 2) is skewed to the right. The median is less than the mean for both the percent of home values (mean 51%; median 34%) and significant market premiums in USD (mean $106; median $28). While the median values are consistent with expectations when compared to estimates from stated preference methods (but weakly not consistent with the averting expenditure method), the mean values are much larger and are not consistent with expectations. This demonstrates that while many hedonic studies estimate market premiums that are reasonable, there are also many studies that find large implausible estimates. The hedonic method, when applied in the developing country context to estimate the marginal WTP for piped water supply, faces systematic challenges.

6.7 Conclusion

Our review of the HPVM literature on household demand for piped water in developing countries suggests that the method is still not well developed in this context, and its application has not generated consistently reliable and valid results. First, we find that the value of piped water is frequently, but not always, capitalized in housing markets. Sixty-three percent of hedonic property models find a significant effect of piped water on home prices. Significant market premiums also estimated have a large range, from -35% to 353%, or -$1.26 to $938. Second, there are challenges to content validity with inconsistent research designs and methods used. While the meta-analysis shows that the hedonic market premiums have relationships with household income consistent with economic theory, the relationships with findings from other non-market valuation methods are inconsistent with theoretical expectations. Construct validity is also challenged when comparing with WTP estimates from stated preference and averting expenditure studies. We find that the estimated hedonic market premiums can, however, be useful, if the identified challenges to reliability, content and construct validity are addressed.

Despite the large range and right skewed distribution, the median market premium of 34%, or $28, not all estimates are entirely implausible when compared to coping costs and stated preference estimates. In returning to our theoretical framework, our findings lead us to conclude with six best practices when applying the hedonic method in valuing piped water supply in developing countries. In Table 6, we assess the extent to which the hedonic papers that focused on water adhered to these best practices. While none of the papers have applied all of the best practices, three papers form the foundation on which future work can improve: Anselin, Lozano-Gracia, Deichmann & Lall (2008), Nauges, Strand & Walker (2008), and Suparman, Folmer & Oud (2016). For future researchers, to construct a valid and reliable hedonic estimate, we suggest the following checklist of best practices:

1. **Select a study site with an even distribution between homes that have piped water access and those that do not.** This would provide a solution to the problem of common support, where there is a lack of comparable homes in the two groups (with and without piped water access). We find a robustly Additionally, if the main independent variable (i.e., piped water supply) is determined for some level of confounders, the common support problem is exacerbated and "inference may be ill-advised" (Cheng et al., (2010); Westreich and Cole, 2010). In the case of water supply, confounders can include income, political power, and cost of supply. At low levels of coverage, piped water access is often first extended to wealthy and politically well-connected neighborhoods. Similarly, at high levels of coverage, homes that remain unconnected frequently belong to the poor or are extremely costly to supply. Solutions are not immediately obvious; the simplest is restriction of the sample being examined but limits the target population for inference (see Westreich and Cole (2010) for more).

2. **Understand the characteristics of water supply, including access, reliability, quality, costs, benefits, and availability of substitutes and complements.** This is important for two reasons. First, we find evidence that these characteristics can affect hedonic market premiums estimated. For example, the inclusion of availability of other water sources in the hedonic model is associated with lower hedonic market premiums. Most authors do not include a description of water supply characteristics (only seven do: Aryeetey-Attoh (1992), Yusuf and Koundouri (2005), Anselin et al. (2008), van den Berg and Nauges (2012), Vásquez (2013), Suparman et al. (2016), Nakamura (2017)); fewer still account for them in the hedonic model. Second, an understanding of water supply characteristics is required for clear author interpretation of the resulting hedonic market premium estimate and consequent comparisons across studies. Is the market premium for an in-home piped water connection that supplies 24/7, potable water at a subsidized rate in a city where other water sources are expensive and require private capital expenditures for storage and treatment? Or is the market premium for a piped water connection that provides water of poor quality intermittently in a city where households can easily and cheaply drill private wells or purchase affordable, potable water from private water vendors operating in a competitive market? Researchers should clearly understand and account for existing costs to the owner of piped water supply, including the existing water tariff (shared or not), connection fees, costs of in home plumbing, and expectations about future tariff changes.
3. **Qualitatively assess housing markets for activity, competitiveness, and equilibrium conditions.** These conditions are necessary for (1) the home price to reflect home and neighborhood characteristics and (2) to interpret the derived marginal implicit prices as marginal willingness to pay.[43] For example, mobility of households (and therefore market

[43] Marginal implicit prices are estimates of marginal willingness to pay under two main conditions: (1) households are in equilibrium given the vector of housing prices and (2) the vector of housing prices clears the market for the given stock of housing (Taylor, 2003). Further requirements include full information on all

activity) varies greatly in developing countries, from 3% to 43% (Strassman, 1991; Malpezzi, 1999). Tenure security, while systematically affecting housing prices, also affects mobility and market activity (Friedman et al., 1988). Systematic differences in housing supply factors can also introduce heterogeneity in markets and affect economic analyses. These factors include: accessibility of housing finance and mortgage rates, prevalence of informality in land markets, government allocation of land and subsidies (Malpezzi, 1999). Without understanding the broader housing market, researchers and readers cannot be assured that the estimates of market premiums for piped water services are unbiased and plausible. The reviewed papers rarely describe these important contextual characteristics necessary to justify the use of the hedonic method and often do not have a reasonable theory for how piped water is capitalized into home values.

4. **Seriously consider the measurement of water services and its interpretation.** Building upon the second point in this checklist, we urge both researchers and readers to thoughtfully and seriously consider how piped water services are being measured, as it affects both the results of the analysis and interpretation. For example, the unusual results reported by Ahmad (2015) (significant and negative market premium for renters and a significant, large, and positive market premium for squatters) can perhaps be explained by how he measured piped water services: as "access to drinking water from any sources maintained by the statutory bodies or non-government organizations." Though interpreted to be piped water, it is not clear if a distinction was made between public taps and private taps. We find that researchers that measure piped water services as a dummy variable report larger market premiums compared to those that use a service bundle of which piped water is one, a lack of piped water services, or use a piped water supply characteristic. There are also sometimes distinctions between

housing prices and attributes; transaction and moving costs at zero; and price vectors that adjust instantaneously to changes in supply or demand (Taylor, 2003).

piped water to the property (as a yard tap) and piped water inside the home, but this is not always made clear. Additionally, the term "access" is not clarified in studies – is it that the household can obtain a private water connection if they so desire or is it that the household currently has a private water connection in their home? Future work needs to incorporate a nuanced understanding of the water supply system when constructing a valid measure for piped water supply in homes.

5. **Omitted variable bias should be carefully considered and mitigated by selecting home and neighborhood characteristics that are generated by different processes (preferably separate from water service provision).** Municipal water services are often generated by similar processes as other public, infrastructure services. As a result, it is especially important to include neighborhood characteristics that are generated by other processes: for example, safety/crime rate; distance to the central business district and markets; availability of cultural and religious centers; quality and/or proximity of primary and secondary schools; and neighborhood income and ethnicity. The papers reviewed generally did not include such neighborhood characteristics, but we found that the inclusion of other infrastructure services does have a positive effect on both the likelihood of a statistically significant market premium for piped water supply and the magnitude.
6. **Address endogeneity, especially in the form of simultaneity, where the increased political power of wealthier neighborhoods brings piped water services to their households.** The "elite-focused culture of governance" is a significant and well-recognized issue in water services provision (Bakker et al., 2008; Tiwale et al., 2018; Alda-Vidal et al., 2018). Simultaneously, access to water services can affect home prices. Estimating only one portion of the model results in endogeneity and therefore biased estimates of the market premium. As a result, simultaneity is of particular importance in estimating market premiums for piped water services. However, this has not been addressed adequately in the literature, as

none of the authors reviewed have accounted for this type of endogeneity. Unsurprisingly, we find that addressing other forms of endogeneity makes it more likely for the HPVM to find a statistically significant market premium for piped water supply.

Table 6.6. Assessment of best practices in hedonic studies with a focus on piped water supply

Study	Address issue of common support	Understand water supply	Assess housing market	Consider measurement of water supply	Mitigate omitted variable bias	Address endogeneity
North & Griffin (1993)		X		X		
Crane, Daniere, & Harwood (1997)		\	X		\	X
Yusuf & Koundouri (2005)		\			X	X
Harapap & Hartono (2007)						X
Nauges, Strand & Walker (2008)		X	X	X		X
Anselin, Lozano-Gracia, Deichmann & Lall (2008)		X	X	X	\	X
Espinoza, Balaguer & Camilla (2009)						
van den Berg & Nauges (2012)		X	X	\		
Vasquez (2013)		X		X		X
Choumert, Stage & Uwera (2014)		X		X		
Choumert, Kere & Lare-Dondarini (2016)		X				X
Suparman, Folmer & Oud (2016)		X		X	X	X
Amoah & Moffatt (2017)		X		X	\	

X – Some consideration
\ – Minimal consideration

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CHAPTER 7: CONCLUSION

Below, I first summarize the major findings and limitations of each individual chapter. Then, I discuss the chapters' findings together and its implications for water supply in Kathmandu and future work.

In Chapter 2, we find that real coping costs more than doubled between 2001 and 2014, from US$5 to US$12 per month (in 2014 prices, or 2% and 3% of household income, respectively). Households responded to the deteriorating condition of the piped water infrastructure by drilling more private wells, installing more storage tanks, and purchasing water from tanker truck and bottled water vendors. These capital investments and expenditures have been accompanied by a decline in time households spend collecting water from outside the home. With respect to coping costs' determinants, we find that having a larger household, higher income, using more water sources, and a private water connection that is perceived to be unreliable is associated with higher coping costs.

Chapter 2 demonstrates that with detailed data collection, it is possible to estimate the many different economic costs associated with coping with a poor water supply. However, there were a few limitations. First, this is an observational study. Though the regression analysis shows that poor reliability has a significant relationship with higher coping costs, we are limited by our research design and cannot make a strong causal argument attributing the overall increase in coping costs to the delay in infrastructure investment. Future work can use a more refined research design; for example, natural experiments can leverage announcements of delays in project completion. Second, our coping costs cannot be interpreted as the short-run lower bound estimates for household willingness to pay. As a result, we cannot predict the welfare improvements for households that have made substantial capital investments. Third, quantities used to calculate coping costs – financial costs, time spent collecting water, amount of water collected, etc. – were all self-reported. Improvements in accuracy of a few key measurements, such as amount of water collected, can be made.

Chapter 3 finds that with more reliable tap water connections, households spend more time collecting water. Initial evidence suggests that the difference is attributable to two things. First, there is more time spent collecting water within a home with a reliable connection because water is available through the tap for longer periods of time. Second, households that have unreliable water connections have shifted away from collecting water outside the home, choosing instead to purchase vended water. As for water collection and labor productivity, we find that more time collecting water is associated with less time spent working, but water collection activities are not associated with employment decisions. These time investments in collecting water do result in higher water consumption. We also find that water collection time patterns closely reflect leisure and chore time patterns.

This is different from what has been found in much of the prior literature and has become common knowledge – that piped water access comes with large time savings. We find, instead, that the characteristics of the piped water connection matter, especially as other private options (wells, vended water) become more common. Time spent collecting water inside the home is becoming more important as households reduce time collecting water outside the home. There are significant policy implications. With intermittent piped water supply, decisions around water supply schedules should consider the effects on those who work and collect water for their households. We need to understand how water is collected inside the home – if other things can be done at the same time and if water collection right before and/or after work is disruptive. Our study begins to address these questions, but we face a few limitations that are centered around measurement. First, we do not directly measure water collection inside the home. Second, our measure of reliability is based on the number of minutes piped water is supplied to the home. If water is supplied on a known schedule, this measure is less valid. Intermittent water supply can still be reliable if water is supplied exactly according to the schedule. Third, we do not examine the correlation between time spent on water collection and the productive time of all household members. As a result, we cannot adjust for how responsibilities are allocated within a household.

Chapter 4 has three major findings. First, household preferences for an increasing block tariff and fixed charges are not easily explained by household socioeconomic characteristics and water use. Second, in modeling household fair water bills, we find that households support a water tariff that has the water bill increasing as water use increases. However, we do not find evidence of household support for an increasing, non-linear relationship between the water bill and water use. Finally, we show that households desire affordable piped water services and water bills that are calculated fairly for everyone. However, we find that the notion of fairness varies – with many considering a discount for those who use less water to be fair, while others consider fair to be one price for all, regardless of the quantity used.

In challenging two major assumptions made by tariff designers, we identify opportunities for tariff reforms to be made more politically and publicly acceptable in Kathmandu, Nepal. Household objectives are assumed to be fairness, equity, affordability, and economic efficiency. We find that some households believe in equity (lower prices for lower levels of consumption), while others desire equality (same price rate for all). There is little evidence that households prefer an affordable water tariff for the poor, with only a few respondents choosing a tariff structure because they believe it "helps poor households." Finally, we demonstrate that households value economic efficiency and affordability for themselves, with many respondents reporting a very low "fair water bill" at all quantities used and a desire for discounts for using less water. We do not explore household notions of economic efficiency at a societal level. Therefore, tariff designers that focus their messaging on affordability and fairness of the water tariff may be better able to garner political and public support for reforms that can help utility managers achieve their own goals of cost recovery and revenue stability.

Chapter 4 has four major limitations, and they provide avenues for future research. First, there does not exist a well-formed theoretical model for how household tariff preferences are formed. We identify relationships with notions of fairness and social justice, cost-minimization, and water conservation, but we do not examine them individually. As a result, it is difficult to separate the individual effects. Second, our study only asks households to provide one answer to the "fair water bill" question. As a result, we are only able to model "fair water bill" as a function of quantity consumed at an aggregate, community level. Future work can examine household-level fair water bill and quantity relationships by asking respondents about fair water bills for multiple different quantities. Third, we caution that these results are specific to Kathmandu, a locale with extreme conditions. While our results suggest that these findings may be robust to different water shortage conditions, further work is needed to test if these results hold under other conditions. Finally, we do not provide information about the quality of water supplied beyond "better service" when asking about the fair water bill. Future work should control for expectations about the quality of service in examining a fair water bill.

In Chapter 5, we find that water vendors in Kathmandu Valley play a critical role in filling the supply gap from an inadequate public water supply – they supply 20% of the water for households and businesses. However, the water vending services provided are expensive, with end users paying approximately 3.4 times as much for vended water as they pay for water from the public piped water system. Though the prices are high, vendor costs of supply are also high. The portions of the water vending supply chain we examined were all quite competitive. Our estimates of net income were not excessive, and there are no constraints on how much water can be extracted and sold, where their products can be sold, to whom their products can be sold, or the prices at which water can be sold. Indeed, when taking into account firm capital investment decisions, we found that many non-integrated vendors were either losing money or not profitable. There are many independent vendors present in the market, and households report that they are not dependent on any one vendor. Though there are professional associations, competitive pressures are too strong for the associations to assert price control.

Chapter 5 has limitations in two areas: data collection and research design. First, the survey instrument relied on self-reported figures based on memory and recall for firm revenue and costs. There have not been studies assessing the presence of systematic bias; however, we speculate that there is not a negligible level of error in reported figures given the granularity of the data we requested. Additionally, we did not have complete data for the bottled water part of the supply chain – the distributing bottled water vendors. Future work in Kathmandu should include these water vendors; future work at other study sites should strive to build a more complete idea of the vending supply chain before constructing the sampling frame. Second, our research design is descriptive. Future work can build upon our findings and explore questions related to causality and advance theoretical understanding.

Chapter 6 shows that the HPVM is not well developed in estimating household demand for piped water in developing countries. Its application has not generated consistently reliable and valid results. Across the literature, the hedonic value of piped water is frequently, but not always, capitalized in housing markets. Sixty-three percent of hedonic property models find a significant effect of piped water on home prices, with market premiums ranging widely – from -35% to 353%, or -$1.26 to $938/month. There are also inconsistent research designs and methods used; there is a lack of consensus around best practices. The resultant right-skewed distribution of market premiums reflects the challenges to reliability and validity. The median market premium of 34% is not entirely implausible when compared to coping costs and stated preference estimates. The chapter concludes with a list of suggested best practices in working toward constructing valid and more reliable hedonic estimates of willingness to pay for piped water services in developing countries.

Chapter 6 faces three major limitations, all stemming from the limited information we have about the hedonic studies. First, we caution that it is challenging to compare hedonic estimates from vastly different water supply systems. There is large knowledge gap from the studies about the characteristics of piped water supply, the financial costs of piped water, and the availability of substitutes and complements. As a result, we are limited in our ability to make comparisons across studies. Second, as illustrated by the theoretical framework, there are many additional determinants of hedonic market premiums for which we have incomplete information. While there is not much that can be done for a meta-analysis, future work using the hedonic method can utilize the framework to draw more considered inferences. Third, there is also limited information to make comparisons between methods – stated preference and averting expenditure methods. More work needs to be done to understand how different non-market valuation methods compare.

7.1 Final Reflections

In this dissertation, I address the two gaps in the literature on delayed water infrastructure and the multi-faceted study of its consequences by illustrating the structure and complexity of (1) how household coping behaviors, expenditures, and policy preferences change over time; (2) the rise of private water vendor businesses and their supply chains; (3) different demands for private water connections across different geographies and water systems. Our comprehensive data collection efforts and research in Kathmandu illustrate the experiences of those most affected by the infrastructure investment delays and poor water supply. We show the extent to which households and private water vendors have invested in coping. Households have spent more on both capital expenditures and their time collecting water inside the home; private individuals have invested substantial capital in starting small and medium sized enterprises selling water.

By examining these narratives holistically, we are better equipped to implement water policies for both the present and the future. For example, our work on tariff reform as it relates to a portion of coping costs can guide present-day tariff reforms as KUKL gears up for the Melamchi Water Supply Project's completion. Furthermore, we can begin to understand the long-term impacts of infrastructure delays – how these delays can shape the development path of water supply services in Kathmandu Valley. When we examine the four dissertation chapters on Kathmandu together, we begin to understand Kathmandu's water development path and its possible future paths. We find some evidence that suggests the rise of an alternative water supply system – one that is independent of the piped water supply system. However, there is also evidence that supports the piped water supply system's continued dominance. Below, I summarize four major insights that rise from our holistic examination of the consequences of delays in investment in Kathmandu's piped water supply system.

First, compared to 2001, households in 2014 have increasingly invested in difficult to reverse private capital – private wells, pumping and treatment systems, storage tanks. When households switch from traditionally reversible coping behaviors (i.e., water collection, purchasing vended water) to irreversible or difficult to reverse ones (i.e., digging a private well, installing a storage tank and pumps), the short run benefits from public water supply improvements are diminished. The incremental value of an improved public water supply system to a household with a private well, pumps, storage tanks, and treatment systems, will be lower. In Kathmandu, we see increased expenditures in both reversible and irreversible coping measures in the last decade. Further work is needed to explore if (1) the investments in private capital substituted for easily reversible behaviors and (2) if household beliefs about public water supply future performance affect their investment behaviors. Then, we would be able to see if widespread private investments can drive a city's development path away from a centralized piped water supply system.

Furthermore, we find evidence that under conditions of intermittent piped water supply, households spend more time collecting water from reliable piped water connections compared to those with unreliable piped water connections. This raises the question of how demand for piped water changes once a household has switched to a decentralized method of water supply – for example, using a private well and/or purchasing vended water, along with their own storage, pumping, and treatment systems. Though these decentralized systems are more expensive and complex, we find that households consequently spend less time collecting water at inconvenient or disruptive times of day. Are these behavioral changes enough to reduce long-term household demand for piped water, illustrating important path dependencies? There are opportunities to study the relationship between private, decentralized water supply and piped water supply. As water vending becomes more widespread, it becomes more important to understand its effects on demand for piped water – and consequently, the benefits of extending piped water systems.

Third, we find that private water vendors have also invested large amounts of capital – in private wells and boreholes, pumps, tanker trucks, water bottling plants, etc. While household purchases of vended water are easily reversible, private water vendors' capital investments are not. With rapid improvement and broad expansion of piped water supply, water vendors may see a decrease in income and profit margins. If private water vendors compete for the same households as the public water utility, negative welfare benefits would accrue to private water vendors with public water supply improvements. Further work is needed to understand improvements in public water supply affect water vending businesses and how proliferation of water vending affects a city's water development path.

Finally, we find that tariff reform in Kathmandu will be challenging but plausible. Households are willing to pay higher tariffs for improved piped water supply, but it is conditional on significant improvements. We also find that many households report a very low fair water bill at all quantities. The willingness of users to engage with the existing public water supply system is key to sustaining its long-term viability. Water tariffs are the main way households interact with a water utility over time, and its reform can be a critical policy tool that improves the relationship between household and water supplier. We find evidence that households with higher perceived monthly expenditures (excluding capital costs) on household water supply state larger “fair water bills.” But these higher tariffs are conditional on significant improvements. Further work is needed to explore if this relationship indeed translates into a higher willingness to pay for piped water services; timing of tariff increases – before or after improvements – should also be explored. A higher household willingness to pay for piped water services after incurring high coping costs would support a different development path. In this path, as alternative, expensive water supply systems become more widespread, the draw of a well-functioning, centralized piped water supply increases because households are more acutely aware of the costs of an inadequate piped water supply.

The first three points illustrate the development and growth of an alternative water supply system – one where private household supply and water vendors dominate. They form initial evidence of path dependence – with positive feedback loops pushing Kathmandu’s residents away from a centralized piped water system. The third point highlights an alternative path forward – one supporting the public water supply system. It is still unclear how these three forces balance and which ones dominate. Further work is needed to understand KUKL’s long-term prospects as the prevailing water supply system for Kathmandu Valley. With this improved understanding, appropriate policy tools such as tariff reform can be better designed. Furthermore, the welfare effects of large private investments in alternative water supply systems need to be considered. Significant private investments may reduce short-term benefits of infrastructure investments due to path dependencies, but they could also increase long-term benefits if households continue to be dissatisfied with alternative, more expensive water supply options. Further research is needed to assess which effect is stronger and if changes in willingness to pay translate into increased revenue streams for the water utility.

The case of Kathmandu is a key example of the consequences of delayed water infrastructure investments and continued deteriorating piped water supply conditions. This dissertation demonstrates that the gap in water supply generated by infrastructure delays can systematically change its economic conditions. Alternative water supply systems can flourish, challenging the existing notion of universal piped water as the dominant end state. Second, through a holistic examination households and private vendors, I show a clear evolution in water supply and household preferences and behavior over time. These insights reveal the limitations of stand-alone, cross-sectional studies, as understanding the dynamics of water supply and human behavior are critical to the design of effective policies.

APPENDIX A: ADDITIONAL DISCUSSION OF REGRESSION RESULTS PRESENTED IN TABLE 2.6

First, we examine the results from Models 3 and 4, for 2001. In Model 3, household income has a positive, statistically significant coefficient, indicating that households with higher incomes have higher coping costs. However, respondent education, gender, and household size do not have statistically significant coefficients. In Model 4, after adding additional explanatory variables, the coefficient on household income remains significant and positive. Using a private water connection has a statistically significant, negative coefficient. In 2001 households that used a private water connection, on average and all else equal, had coping costs that were 252 NPR per month lower than households without private connections. For households using a private well, the coefficient is negative but not statistically significant. Most of the coefficients on the variable describing a household's perceptions of piped water quality are not statistically significant. The only statistically significant coefficients are for the taste of the PWC water in the wet season (negative), health in the dry season (positive), and the reliability of the PWC during the dry season (positive). The explanatory variable describing a household's concern about water issues with respect to other environmental policies does not have a statistically significant association with coping costs.

The results for Model 5 (2014 data with only the exogenous household characteristics) are different compared to those for Model 3. The coefficients on respondent education and household size are significant and positive, while the coefficients on respondent gender and income are not significant. The results for Model 6 (2014 data with the full set of explanatory variables) show that the coefficients on respondent education and household size remain significant and positive. The coefficient on income becomes positive, as for the 2001 models, and significant at the 10% level. The results for model 6 also differ from model 4 for a household's use of a private well and private water connection. In model 6, the coefficient on using a PWC is not significant, while it is significant at the 1% level in model 4. Having and using a private water connection in 2014 is not significantly related to a decrease in coping costs. Additionally, the coefficient on the use of a private well, while not significant, changes from negative (in model 4) to positive (in model 6). The coefficient on number of sources used is positive and significant at the 1% level. For the average household, increasing the number of sources used by one is associated with an increase of 288 NPR per month.

In Model 6, the coefficients on households reporting negative perceptions about health and reliability in the dry season are positive and significant at the 5% level. This implies that as households hold a more negative perception about the health effects and reliability of piped water, coping costs are higher. The coefficient on another measure of reliability, the number of hours of service from the PWC each month has a positive and significant (at the 5% level) coefficient. This is odd because higher levels of service are associated with higher coping costs.

APPENDIX B: CHAPTER 4 SUPPLEMENTAL TABLES

Table B.1. Sample representativeness, proportions as compared to Census 2011

	Kathmandu			Lalitpur			Bhaktapur		
	Census	Survey	Difference	Census	Survey	Difference	Census	Survey	Difference
Households	435,544	950		109,505	272		68,557	78	
House ownership	0.39	0.90	0.5***	0.57	0.97	0.4***	0.66	0.94	0.28***
Outer wall – mud bonded bricks/stone	0.15	0.16	0.01	0.30	0.20	−0.1***	0.38	0.44	0.06
Outer wall – cement bonded bricks/stone	0.80	0.84	0.04***	0.65	0.80	0.15***	0.58	0.46	−0.12**
Roof – RCC	0.77	0.80	0.03*	0.66	0.80	0.14***	0.56	0.59	0.03
Roof – galvanized iron	0.17	0.20	0.03**	0.23	0.19	−0.04	0.31	0.36	0.05
Roof – tile/slate	0.02	0.00	−0.02***	0.06	0.01	−0.05***	0.10	0.05	−0.05
Drinking water source – tap	0.62	0.61	−0.01	0.69	0.44	−0.24***	0.78	0.45	−0.33***
Cooking fuel – wood	0.08	0.00	−0.07***	0.18	0.01	−0.17***	0.25	0.12	−0.14***
Cooking fuel – kerosene	0.03	0.00	−0.03***	0.03	0.00	−0.03**	0.03	0.00	−0.03
Cooking fuel – LP gas	0.88	0.99	0.11***	0.77	0.99	0.21***	0.69	0.87	0.18***
Type of toilet – without toilet	0.01	0.06	0.05***	0.04	0.00	−0.04***	0.03	0.09	0.06***
Type of toilet – flush toilet (sewerage)	0.69	0.91	0.22***	0.45	0.92	0.47***	0.48	0.54	0.06
Type of toilet – flush toilet (septic tank)	0.20	0.02	−0.17***	0.39	0.08	−0.31***	0.38	0.35	−0.03
Facility – radio	0.56	0.49	−0.08***	0.57	0.56	−0.02	0.56	0.56	0
Facility – TV	0.75	0.98	0.23***	0.66	0.97	0.3***	0.83	0.97	0.15***
Facility – computer	0.35	0.70	0.34***	0.33	0.64	0.31***	0.29	0.46	0.17***
Facility – telephone	0.28	0.72	0.44***	0.30	0.61	0.31***	0.25	0.42	0.17***
Facility – mobile phone	0.91	0.99	0.08***	0.86	0.97	0.11***	0.87	0.97	0.11***
Facility – motor	0.05	0.09	0.04***	0.06	0.03	−0.03**	0.04	0.03	−0.01
Facility – motorcycle	0.30	0.66	0.36***	0.33	0.69	0.37***	0.28	0.49	0.21***
Facility – cycle	0.10	0.15	0.05***	0.17	0.36	0.19***	0.13	0.26	0.13***
Facility – refrigerator	0.28	0.77	0.49***	0.27	0.76	0.49***	0.18	0.41	0.23***
Average household size	4.00	5.00	1.00	4.26	5.14	0.88	4.44	5.03	0.59
Population above 5 years of age	0.94	0.96	0.02***	0.94	0.27	−0.67***	0.94	0.08	−0.86***
Literate population	0.81	0.88	0.07***	0.78	0.81	0.03***	0.77	0.71	−0.06***
Educational attainment – primary	0.20	0.09	−0.12***	0.23	0.11	−0.11***	0.23	0.12	−0.12***
Educational attainment – lower secondary	0.15	0.08	−0.06***	0.16	0.11	−0.05***	0.18	0.15	−0.03

Educational attainment – secondary	0.12	0.09	−0.02***	0.12	0.09	−0.03***	0.13	0.12	−0.02
Educational attainment – SLC	0.15	0.14	−0.01**	0.14	0.15	0.01	0.15	0.13	−0.02
Educational attainment – intermediate	0.16	0.16	0.00	0.14	0.12	−0.02**	0.13	0.05	−0.08***
Educational attainment – graduate	0.10	0.08	−0.02***	0.09	0.04	−0.04***	0.06	0.03	−0.03***

Table B.2. Comparing respondents who did not understand IBTs with those who did

	Understand			Did not understand			Difference			
Variable	Obs	Mean	Std.	Obs	Mean	Std.	Mean	SE	t	Pr(|T|>|t|)
fair_bill	1,040	540.9	586.0	243	474.3	821.3	66.7	45.4	1.47	0.14
hyp_usage	1,229	15,952	8,045	271	17,048	8,397	−1,096	544	−2.01	0.04
hyp_usage_sq	1,229	3.2×10^8	2.8×10^8	271	3.6×10^8	3.0×10^8	-4.2×10^7	1.9×10^7	−2.21	0.03
ibt	1,210	0.58	0.49	268	0.90	0.31	−0.31	0.03	−9.96	0.00
consider_ktm	1,229	0.77	0.42	271	0.71	0.45	0.06	0.03	2.10	0.04
change_mind	1,229	0.06	0.24	271	0.08	0.28	−0.02	0.02	−1.33	0.18
ln_income	1,193	10.90	0.77	257	10.99	0.70	−0.08	0.05	−1.61	0.11
nhh	1,229	5.07	2.14	271	4.96	2.05	0.11	0.14	0.78	0.44
resp_edu	1,229	8.09	6.20	271	9.52	6.22	−1.44	0.42	−3.45	0.00
resp_illiterate	1,229	0.23	0.42	271	0.16	0.37	0.07	0.03	2.64	0.01
resp_hhhead	1,229	0.52	0.50	271	0.56	0.50	−0.03	0.03	−1.04	0.30
ln_monthlywaterexp	1,229	5.44	2.27	271	5.42	2.04	0.02	0.15	0.15	0.88
pwc_m3	1,229	2.14	4.33	271	4.11	6.31	−1.97	0.32	−6.19	0.00
priority_water	1,229	0.60	0.49	271	0.43	0.50	0.17	0.03	5.09	0.00

Table B.3. Regressions of fair bill for subsamples of respondents' preferred tariff structure

Explanatory variables	(1) fair_bill (IBT == 1)	(2) fair_bill (IBT == 1)	(3) fair_bill (IBT == 1)	(4) fair_bill (IBT == 0)	(5) fair_bill (IBT == 0)	(6) fair_bill (IBT == 0)
hyp_usage	0.0225	0.0188	0.0184	0.0343**	0.0356**	0.0366**
	(0.0148)	(0.0141)	(0.0145)	(0.0145)	(0.0153)	(0.0156)
hyp_usage_sq	-1.94×10^{-7}	-9.07×10^{-8}	-6.74×10^{-8}	-2.02×10^{-7}	-2.74×10^{-7}	-3.12×10^{-7}
	(4.99×10^{-7})	(4.76×10^{-7})	(4.93×10^{-7})	(4.55×10^{-7})	(4.74×10^{-7})	(4.80×10^{-7})
ln_income		87.10*	76.49		164.3***	146.1***
		(49.00)	(46.50)		(43.61)	(41.32)
nhh		5.484	−0.314		−24.01	−24.79
		(10.81)	(11.39)		(16.61)	(16.87)
resp_edu		−1.768	−1.524		8.365	8.064
		(3.887)	(3.697)		(9.384)	(9.442)
resp_illiterate		−3.159	12.17		86.03	88.39
		(64.00)	(66.17)		(93.16)	(94.67)
resp_hhhead		58.28	34.93		111.3***	110.7***
		(41.72)	(37.57)		(39.71)	(40.53)
ln_monthlywaterexp			49.63***			17.29
			(11.40)			(13.26)
pwc_m3			−8.813			5.401
			(6.512)			(4.788)
priority_water			−85.20**			−6.109
			(37.92)			(60.19)
Constant	207.6*	−774.3	−859.8*	259.1***	−1,584***	−1,496***
	(120.0)	(463.7)	(474.7)	(90.11)	(444.9)	(423.8)
Municipality FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	600	592	592	434	413	413
R^2	0.095	0.113	0.147	0.196	0.233	0.239
F-statistic	15.30	14.48	15.19	13.92	13.40	10.33
Prob > F	0.000	0.000	0.000	0.000	0.000	0.000

Clustered standard errors in parentheses.
*** p < 0.01, ** p < 0.05, * p < 0.1.

Table B.4. Regressions of fair bill on hypothetical monthly usage – entire sample

Variables	(1) fair_bill	(2) fair_bill	(4) fair_bill	(5) fair_bill
hyp_usage	0.0247**	0.0215**	0.0219**	0.0216**
	(0.00928)	(0.00928)	(0.00950)	(0.00919)
hyp_usage_sq	-1.25×10^{-7}	-4.41×10^{-8}	-5.91×10^{-8}	-4.14×10^{-8}
	(2.97×10^{-7})	(3.00×10^{-7})	(3.09×10^{-7})	(3.01×10^{-7})
ln_income		101.9***	82.64**	87.96***
		(32.98)	(31.68)	(29.68)
nhh		−0.988	−4.847	−8.566
		(8.777)	(9.037)	(8.578)
resp_edu		1.084	0.930	2.624
		(3.615)	(3.545)	(3.874)
resp_illiterate		−11.71	−5.376	17.88
		(43.99)	(45.48)	(45.52)
resp_hhhead		50.47	42.60	34.83
		(31.20)	(30.20)	(29.89)
ln_monthlywaterexp			35.14***	37.41***
			(10.60)	(9.496)
pwc_m3			3.159	2.247
			(3.920)	(3.646)
priority_water			−57.21	−65.42
			(39.94)	(39.61)
ibt				−187.7***
				(64.91)
Municipality – Lalitpur	−57.19	−35.29	−12.25	−17.56
	(64.08)	(68.37)	(66.25)	(63.62)
Municipality – Bhaktapur	−243.1***	−181.1***	−79.56	−80.67
	(48.47)	(59.52)	(95.78)	(94.12)
Municipality – Kirtipur	−300.9***	−256.8***	−161.3***	−135.5***
	(45.09)	(43.37)	(48.52)	(40.03)
Municipality – Madhyapur Thimi	−115.3*	−57.13	−53.18	−32.57
	(66.06)	(67.14)	(67.59)	(60.91)
Constant	215.9***	−918.7***	−869.7***	−810.3**
	(71.18)	(315.6)	(319.9)	(312.5)
Observations	1,283	1,243	1,243	1,237
R^2	0.086	0.100	0.114	0.132
F-statistic	18.62	13.04	14.41	14.50
Prob > F	0.000	0.000	0.000	0.000

Clustered standard errors in parentheses.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table B.5. Regressions of fair bill on hypothetical monthly usage – entire sample, with the check variable

Variables	(1) fair_bill	(2) fair_bill	(3) fair_bill	(4) fair_bill
check_understanding	−147.9**	−143.9*	−155.0**	−97.96
	(73.40)	(73.73)	(73.77)	(81.89)
hyp_usage	0.0249***	0.0217**	0.0223**	0.0219**
	(0.00901)	(0.00905)	(0.00927)	(0.00906)
hyp_usage_sq	-1.17×10^{-7}	-3.64×10^{-8}	-5.80×10^{-8}	-4.33×10^{-8}
	(2.91×10^{-7})	(2.95×10^{-7})	(3.04×10^{-7})	(2.99×10^{-7})
ln_income		101.3***	81.42**	86.54***
		(32.86)	(31.28)	(29.16)
nhh		−1.148	−5.046	−8.249
		(8.683)	(8.912)	(8.417)
resp_edu		1.522	1.315	2.661
		(3.594)	(3.516)	(3.816)
resp_illiterate		−4.767	1.885	19.73
		(46.95)	(48.56)	(46.89)
resp_hhhead		54.28*	47.03	38.61
		(32.15)	(31.37)	(31.75)
ln_monthlywaterexp			33.28***	35.93***
			(10.44)	(9.536)
pwc_m3			4.853	3.416
			(3.856)	(3.704)
priority_water			−68.01*	−71.13*
			(39.10)	(38.76)
ibt				−166.4**
				(70.64)
Constant	394.2***	−745.0**	−664.9**	−686.8**
	(126.9)	(291.8)	(296.7)	(281.3)
Municipality FE	Yes	Yes	Yes	Yes
Observations	1,283	1,243	1,243	1,237
R^2	0.094	0.108	0.122	0.135
F-statistic	16.23	12.79	14.99	15.22
Prob > F	0.000	0.000	0.000	0.000

Clustered standard errors in parentheses.
*** p < 0.01, ** p < 0.05, * p < 0.1.

APPENDIX C: CHAPTER 5 SUPPLEMENTAL TABLES

Table C.1. Firm-level profits of vendors with only commercial water sources – US$/month (excluded observations in gray)

Vendor ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Dry season															
Revenue	512	455	354	543	758	808	783	1,105	1,516	2,589	758	1,642	76	1,213	3,208
Product costs	21	0	21	32	0	53	0	0	0	32	211	211	0	0	211
Supply chain costs	867	425	0	0	182	103	30	43	173	455	1,516	2,166	509	1,516	2,816
Direct labor costs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gross margin	-376	30	333	512	576	653	753	1,062	1,342	2,103	-969	-735	-434	-304	182
Overhead and management	6	0	147	105	0	168	0	0	316	211	421	126	0	474	442
Maintenance and repairs	0	105	0	0	105	53	0	158	0	53	0	0	0	211	0
Rent and utilities	105	37	105	158	126	421	84	158	105	211	2,158	316	1	684	168
Other	15	0	0	0	0	5	5	5	32	11	11	0	0	2	36
EBITDA	-502	-112	80	248	344	5	663	741	890	1,619	-3,559	-1,177	-434	-1,674	-465
Depreciation	678	76	927	1,464	84	115	27	29	532	213	2,166	1,985	54	5,109	781
EBIT	-1,180	-188	-847	-1,215	260	-109	636	712	358	1,405	-5,725	-3,162	-488	-6,783	-1,245
Taxes	30	0	0	0	0	0	9	9	4	11	70	0	12	0	13
Interest	0	92	0	0	0	0	145	0	807	0	0	0	0	221	77
Net income	-1,210	-280	-847	-1,215	260	-109	483	703	-453	1,394	-5,795	-3,162	-500	-7,004	-1,335
Gross margin/revenue	-0.73	0.07	0.94	0.94	0.76	0.81	0.96	0.96	0.89	0.81	-1.28	-0.45	-5.72	-0.25	0.06
EBITDA/revenue	-0.98	-0.25	0.23	0.46	0.45	0.01	0.85	0.67	0.59	0.63	-4.70	-0.72	-5.73	-1.38	-0.14
EBIT/revenue	-2.31	-0.41	-2.39	-2.24	0.34	-0.14	0.81	0.64	0.24	0.54	-7.55	-1.93	-6.44	-5.59	-0.39
Wet season															
Revenue	568	202	354	543	152	303	707	575	1,263	872	455	1,263	76	543	3,069
Product costs	21	0	21	32	0	53	0	0	0	32	211	211	0	0	211

Supply chain costs	867	425	0	0	182	103	30	43	173	455	1,516	2,166	509	1,516	2,816
Direct labor costs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gross margin	-319	-222	333	512	-30	148	677	531	1,090	385	-1,272	-1,114	-434	-973	43
Overhead and management	6	0	147	105	0	168	0	0	316	211	421	126	0	474	442
Maintenance and repairs	0	105	0	0	105	53	0	158	0	53	0	0	0	211	0
Rent and utilities	105	37	105	158	126	421	84	158	105	211	2,158	316	1	684	168
Other	15	0	0	0	0	5	5	5	32	11	11	0	0	2	36
EBITDA	-446	-365	80	248	-262	-500	588	210	637	-99	-3,862	-1,556	-434	-2,343	-604
Depreciation	678	76	927	1,464	84	115	27	29	532	213	2,166	1,985	54	5,109	781
EBIT	-1,123	-441	-847	-1,215	-346	-615	560	181	105	-313	-6,028	-3,541	-488	-7,452	-1,384
Taxes	30	0	0	0	0	0	9	9	4	11	70	0	12	0	13
Interest	0	92	0	0	0	0	145	0	807	0	0	0	0	221	77
Net income	-1,153	-533	-847	-1,215	-346	-615	407	172	-705	-324	-6,098	-3,541	-500	-7,673	-1,474
Gross margin/revenue	-0.56	-1.10	0.94	0.94	-0.20	0.49	0.96	0.92	0.86	0.44	-2.80	-0.88	-5.72	-1.79	0.01
EBITDA/revenue	-0.78	-1.80	0.23	0.46	-1.73	-1.65	0.83	0.37	0.50	-0.11	-8.49	-1.23	-5.73	-4.31	-0.20
EBIT/revenue	-1.98	-2.18	-2.39	-2.24	-2.28	-2.03	0.79	0.32	0.08	-0.36	-13.26	-2.80	-6.44	-13.72	-0.45
ROA	-0.06%	-0.38%	0.05%	0.13%	0.33%	-1.26%	1.41%	0.51%	0.60%	7.99%	-17.41%	-1.23%	-0.67%	-1.08%	-0.42%
Start year (source)	2006	2010	2011	2013	2010	2012	2011	1999	2012	2006	2008	2010	2002	2009	2009

Table C.2. Firm-level profits of vendors with commercial water sources and tanker trucks – US$/month (excluded observations in gray)

Vendor ID	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Dry season																		
Revenue	3,613	2,678	2,905	2,122	2,451	2,912	5,608	4,926	8,046	5,406	7,579	7,939	6,505	6,878	6,922	11,571	2,274	4,194
Product costs	421	562	728	0	32	303	105	16	5	5	53	53	0	0	21	0	53	303
Supply chain costs	2,275	771	919	491	771	780	2,777	1,759	3,553	1,135	1,630	2,010	894	1,085	466	1,249	3,085	3,579
Direct labor costs	932	522	362	596	379	348	653	964	708	386	1,215	848	414	582	1,017	1,042	255	358
Gross margin	-15	823	897	1,035	1,269	1,480	2,073	2,187	3,780	3,880	4,681	5,028	5,197	5,211	5,418	9,279	-1,119	-46
Overhead and management	316	0	0	0	105	253	158	526	129	68	316	105	189	337	0	947	189	84
Maintenance and repairs	116	263	211	158	126	105	316	4,211	421	158	316	211	158	421	158	632	0	316
Rent and utilities	1,105	316	84	32	168	189	32	242	474	37	421	789	105	137	321	368	400	105
Other selling costs	85	0	0	22	54	22	28	111	64	25	70	47	0	85	45	119	47	47
EBITDA	-1,637	244	602	824	814	911	1,540	-2,903	2,692	3,592	3,558	3,875	4,745	4,231	4,895	7,213	-1,755	-599
Depreciation	248	929	245	460	176	322	232	465	1,176	548	305	1,835	445	442	563	1,275	1,574	685
EBIT	-1,885	-685	358	363	638	589	1,308	-3,368	1,516	3,044	3,254	2,040	4,300	3,789	4,331	5,938	-3,329	-1,284
Taxes	12	37	22	114	26	35	26	26	45	61	48	2	0	118	14	44	2	16
Interest	289	0	0	53	205	614	0	63	211	98	254	0	0	0	224	0	0	0
Net income	-2,187	-721	336	197	407	-60	1,281	-3,458	1,261	2,885	2,952	2,038	4,300	3,670	4,093	5,894	-3,331	-1,300
Gross margin/revenue	0.00	0.31	0.31	0.49	0.52	0.51	0.37	0.44	0.47	0.72	0.62	0.63	0.80	0.76	0.78	0.80	-0.49	-0.01
EBITDA/revenue	-0.45	0.09	0.21	0.39	0.33	0.31	0.27	-0.59	0.33	0.66	0.47	0.49	0.73	0.62	0.71	0.62	-0.77	-0.14
EBIT/revenue	-0.52	-0.26	0.12	0.17	0.26	0.20	0.23	-0.68	0.19	0.56	0.43	0.26	0.66	0.55	0.63	0.51	-1.46	-0.31
Wet season																		
Revenue	2,526	1,364	1,377	1,465	1,175	2,116	2,804	1,819	3,865	3,916	3,701	6,373	4,775	1,459	5,457	5,293	1,996	2,880
Product costs	421	360	253	0	32	227	105	16	5	5	53	53	0	0	21	0	53	101
Supply chain costs	1,668	558	919	627	407	650	1,685	1,152	1,854	771	1,266	1,525	677	449	399	1,245	2,964	3,215
Direct labor costs	602	345	244	404	268	297	432	596	420	298	814	672	337	405	928	688	225	211
Gross margin	-165	101	-39	434	467	942	582	55	1,585	2,841	1,568	4,123	3,760	605	4,108	3,359	-1,246	-646
Overhead and management	316	0	0	0	53	253	158	526	129	68	316	105	189	337	0	947	189	84
Maintenance and repairs	116	263	211	158	126	105	316	4,211	421	158	316	211	158	421	158	632	0	316
Rent and utilities	1,105	316	84	32	168	189	32	242	474	37	421	789	105	137	321	368	400	105

Other selling costs	85	0	0	22	54	22	28	111	64	25	70	47	0	85	45	119	47	47
EBITDA	-1,787	-478	-333	223	66	372	49	-5,035	497	2,554	445	2,971	3,308	-375	3,584	1,293	-1,882	-1,199
Depreciation	248	929	245	460	176	322	232	465	1,176	548	305	1,835	445	442	563	1,275	1,574	685
EBIT	-2,035	-1,407	-578	-238	-111	50	-184	-5,501	-679	2,006	141	1,136	2,862	-817	3,021	18	-3,457	-1,884
Taxes	12	37	22	114	26	35	26	26	45	61	48	2	0	118	14	44	2	16
Interest	289	0	0	53	205	614	0	63	211	98	254	0	0	0	224	0	0	0
Net income	-2,336	-1,444	-600	-404	-342	-599	-210	-5,590	-934	1,847	-162	1,134	2,862	-935	2,783	-26	-3,458	-1,900
Gross margin/revenue	-0.07	0.07	-0.03	0.30	0.40	0.45	0.21	0.03	0.41	0.73	0.42	0.65	0.79	0.41	0.75	0.63	-0.62	-0.22
EBITDA/revenue	-0.71	-0.35	-0.24	0.15	0.06	0.18	0.02	-2.77	0.13	0.65	0.12	0.47	0.69	-0.26	0.66	0.24	-0.94	-0.42
EBIT/revenue	-0.81	-1.03	-0.42	-0.16	-0.09	0.02	-0.07	-3.02	-0.18	0.51	0.04	0.18	0.60	-0.56	0.55	0.00	-1.73	-0.65
ROA	-5.78%	0.17%	1.74%	0.90%	3.17%	0.76%	1.06%	-12.33%	5.65%	2.18%	7.93%	1.97%	10.50%	13.37%	9.00%	14.64%	-1.49%	-0.63%
Start year (source)	2010	2003	2009	2004	2012	2008	2012	2004	1999	2006	2010	2006	2009	2007	2009	1998	2011	2008
Start year (tanker trucks)	2010	2003	2009	2004	2009	2008	2012	2004	1999	2008	2010	2009	2009	2007	2009	1999	2011	2011

Table C.4. Firm-level profits of vendors with only tanker trucks – US$/month

Vendor ID	34	35	36	37	38	39	40	41	42	43	44	45	46	47
Dry season														
Revenue	3,234	2,122	7,629	2,501	6,063	2,931	10,358	1,819	2,274	1,895	2,122	2,274	2,274	2,956
Product costs	354	227	1,819	531	884	619	1,996	379	455	379	531	455	455	455
Supply chain costs	4,604	3,694	6,540	2,002	4,614	1,906	4,580	728	910	758	948	910	910	1,638
Direct labor costs	559	360	774	349	889	549	3,659	544	659	453	307	512	501	445
Gross margin	-2,283	-2,159	-1,503	-381	-325	-144	124	169	250	305	337	398	408	418
Overhead and management	105	84	126	0	105	0	337	84	84	84	42	84	84	47
Maintenance and repairs	526	263	474	105	421	263	105	316	316	368	158	316	211	232
Rent and utilities	0	0	42	0	0	221	0	0	0	0	0	0	0	0
Other selling costs	74	40	85	36	60	54	9	39	41	44	41	41	41	23
EBITDA	-2,988	-2,546	-2,230	-522	-911	-683	-327	-270	-191	-192	96	-44	72	117
Depreciation	158	59	162	357	138	309	417	141	101	110	148	118	59	165
EBIT	-3,146	-2,606	-2,392	-879	-1,049	-991	-745	-411	-292	-302	-53	-162	13	-48
Taxes	25	12	46	120	25	38	3	0	26	7	15	12	7	15
Interest	61	0	92	0	0	281	0	86	0	0	137	0	68	0
Net income	-3,232	-2,618	-2,531	-999	-1,073	-1,310	-748	-497	-318	-309	-205	-174	-62	-64
Gross margin/revenue	-0.71	-1.02	-0.20	-0.15	-0.05	-0.05	0.01	0.09	0.11	0.16	0.16	0.17	0.18	0.14
EBITDA/revenue	-0.92	-1.20	-0.29	-0.21	-0.15	-0.23	-0.03	-0.15	-0.08	-0.10	0.05	-0.02	0.03	0.04
EBIT/revenue	-0.97	-1.23	-0.31	-0.35	-0.17	-0.34	-0.07	-0.23	-0.13	-0.16	-0.02	-0.07	0.01	-0.02
Wet season														
Revenue	1,213	707	4,093	2,501	3,032	1,971	4,547	1,213	1,516	1,516	1,061	1,137	1,137	1,642
Product costs	133	76	985	531	442	417	935	253	303	303	227	227	227	253
Supply chain costs	2,177	1,571	3,629	2,002	1,885	1,906	4,580	485	607	607	493	455	455	910
Direct labor costs	368	208	426	349	574	461	1,905	408	541	394	201	335	324	292
Gross margin	-1,465	-1,147	-948	-381	131	-814	-2,872	67	65	212	140	120	130	188

Overhead and management	0	42	126	0	105	0	337	84	84	84	42	84	84	47
Maintenance and repairs	526	263	474	105	421	263	105	316	316	368	158	316	211	232
Rent and utilities	0	0	42	0	0	221	0	0	0	0	0	0	0	0
Other selling costs	74	40	85	36	60	54	9	39	41	44	41	41	41	23
EBITDA	-2,065	-1,492	-1,674	-522	-455	-1,352	-3,323	-372	-376	-284	-101	-321	-206	-114
Depreciation	158	59	162	357	138	309	417	141	101	110	148	118	59	165
EBIT	-2,223	-1,552	-1,837	-879	-593	-1,661	-3,740	-513	-477	-395	-250	-440	-264	-279
Taxes	25	12	46	120	25	38	3	0	26	7	15	12	7	15
Interest	61	0	92	0	0	281	0	86	0	0	137	0	68	0
Net income	-2,309	-1,564	-1,975	-999	-617	-1,979	-3,743	-599	-503	-401	-402	-451	-339	-294
Gross margin/revenue	-1.21	-1.62	-0.23	-0.15	0.04	-0.41	-0.63	0.06	0.04	0.14	0.13	0.11	0.11	0.11
EBITDA/revenue	-1.70	-2.11	-0.41	-0.21	-0.15	-0.69	-0.73	-0.31	-0.25	-0.19	-0.10	-0.28	-0.18	-0.07
EBIT/revenue	-1.83	-2.19	-0.45	-0.35	-0.20	-0.84	-0.82	-0.42	-0.31	-0.26	-0.24	-0.39	-0.23	-0.17
ROA	-51.14%	-24.73%	-9.35%	-2.47%	-8.92%	-3.22%	-2.96%	-1.86%	-1.61%	-1.70%	0.39%	-0.89%	0.02%	0.40%
Start year (tanker trucks)	2004	2008	2009	2007	2007	2009	2005	2009	2007	2003	2009	2007	2011	2004

Table C.4. Firm-level profits of vendors with only tanker trucks – US$/month (continued)

Vendor ID	50	51	52	53	54	55	56	57	58	59	60	61	62	63
Dry season														
Revenue	2,842	5,154	6,139	3,486	3,183	4,825	1,819	2,122	3,789	2,829	2,779	2,425	1,819	3,739
Product costs	789	985	960	455	606	1,067	379	455	455	531	379	409	379	821
Supply chain costs	1,300	2,548	2,972	1,820	1,360	2,470	265	592	1,760	1,100	1,061	755	106	1,352
Direct labor costs	318	1,120	1,705	585	589	643	491	261	757	353	453	316	278	499
Gross margin	435	501	501	627	627	645	684	814	817	847	886	945	1,056	1,067
Overhead and management	0	337	253	316	211	0	84	32	105	42	84	42	74	253
Maintenance and repairs	158	316	316	316	105	263	211	105	484	179	421	158	211	211
Rent and utilities	0	0	0	0	0	0	0	42	0	13	0	11	0	0
Other selling costs	30	137	46	41	42	45	39	17	92	31	41	39	46	61
EBITDA	247	-289	-113	-46	269	337	350	618	135	582	339	696	726	543
Depreciation	228	161	294	91	115	345	118	164	158	43	30	169	102	240
EBIT	20	-450	-406	-137	154	-8	232	455	-23	539	309	527	624	304
Taxes	105	54	15	15	22	170	13	92	37	20	15	16	35	65
Interest	0	0	0	0	0	0	184	0	142	47	0	164	57	0
Net income	-86	-503	-422	-153	132	-178	34	363	-202	472	294	347	532	239
Gross margin/revenue	0.15	0.10	0.08	0.18	0.20	0.13	0.38	0.38	0.22	0.30	0.32	0.39	0.58	0.29
EBITDA/revenue	0.09	-0.06	-0.02	-0.01	0.08	0.07	0.19	0.29	0.04	0.21	0.12	0.29	0.40	0.15
EBIT/revenue	0.01	-0.09	-0.07	-0.04	0.05	0.00	0.13	0.21	-0.01	0.19	0.11	0.22	0.34	0.08
Wet season														
Revenue	1,667	3,436	4,800	1,743	3,183	3,057	909	1,061	1,617	1,213	1,667	1,213	1,213	2,274
Product costs	474	657	745	227	606	676	189	171	208	227	227	205	253	505
Supply chain costs	1,170	1,698	2,335	910	1,360	2,166	133	486	851	493	637	391	71	1,170
Direct labor costs	241	943	1,484	408	589	478	314	173	493	205	335	205	231	375
Gross margin	-217	137	235	198	627	-264	274	232	65	287	468	412	658	223
Overhead and management	0	337	253	316	211	0	84	32	158	42	84	42	74	253
Maintenance and repairs	158	316	316	316	105	263	211	105	484	179	421	158	211	211
Rent and utilities	0	0	0	0	0	0	0	42	0	13	0	11	0	0
Other selling costs	30	137	46	41	42	45	39	17	92	31	41	39	46	61
EBITDA	-405	-652	-379	-475	269	-571	-61	36	-669	23	-78	163	328	-300

Depreciation	228	161	294	91	115	345	118	164	158	43	30	169	102	240
EBIT	-633	-813	-672	-566	154	-916	-179	-128	-827	-20	-108	-6	227	-540
Taxes	105	54	15	15	22	170	13	92	37	20	15	16	35	65
Interest	0	0	0	0	0	0	184	0	142	47	0	164	57	0
Net income	-738	-867	-688	-582	132	-1,086	-376	-220	-1,006	-88	-123	-186	134	-605
Gross margin/revenue	-0.13	0.04	0.05	0.11	0.20	-0.09	0.30	0.22	0.04	0.24	0.28	0.34	0.54	0.10
EBITDA/revenue	-0.24	-0.19	-0.08	-0.27	0.08	-0.19	-0.07	0.03	-0.41	0.02	-0.05	0.13	0.27	-0.13
EBIT/revenue	-0.38	-0.24	-0.14	-0.32	0.05	-0.30	-0.20	-0.12	-0.51	-0.02	-0.06	-0.01	0.19	-0.24
ROA	0.50%	-1.86%	-0.74%	-0.97%	1.20%	0.34%	1.78%	0.43%	-0.26%	7.92%	3.67%	3.96%	5.91%	1.74%
Start year (tanker trucks)	2008	2008	2006	2010	1992	2009	2010	2011	2012	2011	2010	2009	2009	2007

Table C.4. Firm-level profits of vendors with only tanker trucks – US$/month (continued)

Vendor ID	64	65	66	67	68	69	70	71	72	73	74	75	76	77
Dry season														
Revenue	2,829	1,971	4,244	3,158	2,299	2,299	3,284	3,789	6,859	6,114	3,411	4,168	9,549	9,752
Product costs	303	379	808	379	442	442	379	442	1,667	1,895	455	657	1,251	1,415
Supply chain costs	926	133	2,026	1,061	124	124	758	823	2,183	728	152	136	3,087	3,109
Direct labor costs	437	289	180	453	373	363	506	512	683	1,065	108	439	1,345	1,226
Gross margin	1,163	1,170	1,230	1,265	1,360	1,370	1,641	2,013	2,326	2,426	2,696	2,936	3,867	4,002
Overhead and management	105	84	84	84	84	74	105	53	0	29	42	0	142	215
Maintenance and repairs	105	263	316	421	263	211	158	211	211	211	211	211	316	526
Rent and utilities	0	0	0	0	0	0	0	0	0	0	0	53	0	0
Other selling costs	27	39	63	46	43	43	30	35	33	54	24	0	60	60
EBITDA	926	783	767	714	969	1,043	1,348	1,715	2,082	2,131	2,419	2,673	3,349	3,201
Depreciation	131	102	207	67	124	40	81	69	320	777	92	317	235	692
EBIT	794	682	560	647	845	1,003	1,267	1,646	1,762	1,354	2,328	2,356	3,114	2,510
Taxes	11	13	114	7	13	13	12	11	41	22	7	23	25	22
Interest	114	0	84	0	74	61	74	105	181	0	25	395	0	0
Net income	669	668	361	641	758	928	1,181	1,530	1,541	1,332	2,295	1,938	3,090	2,488
Gross margin/revenue	0.41	0.59	0.29	0.40	0.59	0.60	0.50	0.53	0.34	0.40	0.79	0.70	0.40	0.41
EBITDA/revenue	0.33	0.40	0.18	0.23	0.42	0.45	0.41	0.45	0.30	0.35	0.71	0.64	0.35	0.33
EBIT/revenue	0.28	0.35	0.13	0.20	0.37	0.44	0.39	0.43	0.26	0.22	0.68	0.57	0.33	0.26
Wet season														
Revenue	1,061	985	1,971	1,895	1,314	1,314	1,314	1,137	1,857	3,234	1,137	2,476	4,244	5,179
Product costs	114	189	379	227	253	253	152	133	417	985	152	417	556	758
Supply chain costs	380	66	964	637	71	71	364	412	1,619	485	152	134	1,571	1,592
Direct labor costs	253	218	128	335	254	248	289	211	294	800	64	333	740	815
Gross margin	314	511	499	696	736	742	509	381	-473	963	769	1,592	1,378	2,014
Overhead and management	53	84	84	84	84	74	53	53	0	29	42	0	95	143
Maintenance and repairs	105	263	316	421	263	211	158	211	211	211	211	211	316	526
Rent and utilities	0	0	0	0	0	0	0	0	0	0	0	53	0	0
Other selling costs	27	39	63	46	43	43	30	35	33	54	24	0	60	60
EBITDA	129	125	36	145	346	415	269	84	-717	669	493	1,329	907	1,285

Depreciation	131	102	207	67	124	40	81	69	320	777	92	317	235	692
EBIT	-2	23	-172	78	222	375	188	15	-1,037	-108	401	1,011	673	593
Taxes	11	13	114	7	13	13	12	11	41	22	7	23	25	22
Interest	114	0	84	0	74	61	74	105	181	0	25	395	0	0
Net income	-127	10	-370	72	135	301	102	-101	-1,258	-130	369	594	648	571
Gross margin/revenue	0.30	0.52	0.25	0.37	0.56	0.57	0.39	0.34	-0.25	0.30	0.68	0.64	0.32	0.39
EBITDA/revenue	0.12	0.13	0.02	0.08	0.26	0.32	0.20	0.07	-0.39	0.21	0.43	0.54	0.21	0.25
EBIT/revenue	0.00	0.02	-0.09	0.04	0.17	0.29	0.14	0.01	-0.56	-0.03	0.35	0.41	0.16	0.11
ROA	6.67%	5.84%	1.71%	7.19%	6.31%	6.43%	8.47%	10.47%	5.67%	3.18%	20.28%	2.37%	16.02%	13.47%
Start year (tanker trucks)	2009	2009	2011	2009	2010	2010	2011	2012	2009	2007	2009	2011	2004	2001

APPENDIX D: PHOTOGRAPHS OF BOTTLE WATER FACILITIES IN KATHMANDU (2014)

APPENDIX E: GROUNDWATER CONTAMINATION STUDIES

Early studies examining groundwater contamination do not find a statistically significant effect on residential properties (Malone and Barrows, 1990; Page and Rabinowitz, 1993; Dotzour, 1997). The authors speculate that the lack of capitalization of groundwater contamination can be due to three reasons: (1) sellers delaying sales but not decreasing values (Malone and Barrows, 1990), (2) owners connected to piped supply perceiving that there are not health risks or (3) property owners are not liable costs of cleanup, as Superfund site property owners can be (Page and Robinowitz, 1993; Dotzour, 1997). Guignet, Walsh, and Northcutt (2016) caution inference using their results, highlighting simple econometric identification strategies, small sample sizes, and coarse measures of water quality. Despite this, the authors make salient points about causal paths.

More recent hedonic studies estimating impacts of groundwater contamination find statistically significant effects that diminish over time (Case et al., 2006; Boyle et al., 2010; Guignet, Walsh, and Northcutt, 2016). Case et al. (2006) find an average decrease of 4.7% in prices that occurs only after the volatile organic compound contamination becomes publicly known; the effect disappears after five years. Case et al. (2006) attribute this decline in in the discount associated with groundwater contamination is likely to signal a “decline in the market’s assessment of the value of clean groundwater, rather than a decline in the physical severity of the contamination.” However, it should be noted that local water providers immediately stopped using the contaminated water source and remediation efforts were ongoing. Boyle et al. (2010) also find a temporary 0.5-1.0% decline in home price for each 0.001 milligram per liter of arsenic above the regulatory standard detected in private wells, where the average arsenic concentration was 0.086

mg/L, or 0.036 mg/L more than the regulatory standard.[44] They speculate that the dissipation of the price effect after three years could be due to the installation of in-home water treatment systems or to the "dissipation of perceived risk once the media coverage stopped." Guignet, Walsh, and Northcutt (2016) find that contamination of groundwater (from nitrogen, arsenic, and ethylene bromide) that exceeds health standards corresponds to an average 2-6% depreciation in home prices, with higher costs of 15% decreases at levels twice the standard. They also find that the effect diminishes over time, with the presence of a robust, state-wide mitigation strategy.

Only one study by Christensen et al. (2018) examines the impacts of contaminated drinking water supplied by piped systems. While still not an estimate for the value of a piped water connection, it is more closely related than estimating the effects of groundwater contamination. Christensen et al. (2018) use difference-in-differences and event study research designs to robustly identify the impacts of a water supply crisis and estimate welfare effects using home values in Flint, Michigan. The authors find that when compared with control housing markets, average home values in Flint decrease by 33% (Christensen et al., 2018). As this water contamination crisis is still on-going, it is not clear what the long-term effects are, if any, on home prices. It is also difficult to separate the effect of lead contamination from systematic governance failures in Flint, Michigan.[45] The authors "find little evidence of differential impacts across homes within Flint," which would have made a stronger argument for attributing the decrease in home prices to lead contamination rather than a failed government at multiple levels.

[44] The mean arsenic concentration of the nearest test result in excess of the regulatory standard (0.05 mg/L) was reported to be 86.36 parts per billion (ppb), or 0.086 mg/L. The mean increase in arsenic concentration is 36.36 ppb, or 0.036 mg/L.

[45] The authors list the loss of trust in local government as an additional economic impact of the crisis, but other researchers argue that the Flint water crisis was a product of environmental racism and financial stress, reflective of larger government failures (Campbell et al., 2016).